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USE OF THE PETTER AV1 DIESEL ENGINE FOR TESTING ADDITIVE TREATED OILS

By A. Towle * and P. E. B. Vaile * (Associate Fellow)

Summary

This paper shows how the Petters AV1 laboratory oil test engine can be run on a 120-hour test procedure to provide a relatively simple and inexpensive method of comparing the performance of both straight and treated oils. It is shown that the results so achieved line up well with service experience, and the paper demonstrates that the engine can be used to predict the performance of oils on the Caterpillar L.1 test with a reasonable degree of certainty. Reference is also made to the use of the AV1 unit for testing production batches of heavy duty additives.

The company with which the authors are associated have supported the development of the test procedure and the carrying out of about 700 tests to date, and regard the experience gained and results achieved as well worth the considerable expenditure involved. Proof that this view is shared by others lies in the increasing adoption of the engine as an oil test unit by laboratories both in the U.K. and abroad.

Introduction

It should first be emphasized that any engine test of a lubricating oil is by no means a precision test. In spite of the very considerable efforts by chemists and physicists, it has not yet been possible to devise chemical or physical tests which satisfactorily predict the service performance of crankcase lubricating oils, and it is now generally recognized that the main qualities required from these oils can be evaluated only by engine tests. The qualities usually evaluated include the following :—

(*a*) prevention of the formation of excessive deposits of carbon, lacquer, and other materials in the piston ring grooves and on the rings themselves, which might cause the rings to stick in their grooves;

(*b*) prevention of the formation of carbon, sludge, and lacquer on the piston skirt or elsewhere in the engine, which could result in piston or bearing seizure;

(*c*) prevention of bearing corrosion;

(*d*) reduction in the wear of cylinder liners, piston rings, piston ring grooves, and other parts of the engine.

Since it is well known that all the above troubles occur with different degrees of severity at different coolant and oil temperatures and under different conditions of load and speed, in addition to varying with the type and design of engine, it is obvious that any one test procedure run on one particular engine under selected conditions can at the best be only a compromise. Generally the test conditions and engines used must be selected to give results which bear some relationship to average conditions in service.

* Anglamol Ltd.

The American Army Ordnance, in their 2104 series of tests, recognize this fact, and specify two tests, *i.e.*, a 480-hour endurance test on a Caterpillar single-cylinder diesel engine under moderate conditions of speed, load, and temperature to evaluate items (*a*), (*b*), and (*d*) (known as the CRC L-1-545 or AXS-1551 test), and a short duration 36-hour test (known as the CRC L-4-545 or AXS-1554 test) carried out at high temperature on a Chevrolet six-cylinder petrol engine chiefly to evaluate item (*c*) but partially also to evaluate high temperature sludge and varnish formation. Generally tests carried out at low coolant and oil temperatures to simulate door to door delivery service have given poor reproducibility and tend to be more a test of the fuel than the oil; consequently engine test laboratories have concentrated more on high than on low temperature tests.

The Petters AV1 engines described in this paper have been used in the Anglamol Technical Service Laboratories as oil test engines for the past five years, and some 700 tests have been carried out on them. In general, they have given extremely good service, and results have been obtained which are reproducible in themselves, line up well with certain prolonged service conditions, and which within limits can be made to predict the behaviour of a given oil on the Caterpillar L.1 test. It is believed that at present they represent the best value in engine testing expenditure, and this is substantiated by the fact that at least fifty examples of this engine are known to be currently in use by laboratories in the U.K. and in five Continental countries.

History and Advantages of the Unit

Early in 1946 one of the authors was faced with the problem of testing production batches of the first lubricating oil additives in large-scale manufacture in the U.K. In view of their wide acceptance it was obvious that Caterpillar and Chevrolet units would be necessary for reference purposes; but it was equally obvious that there would be delay in obtaining and installing these engines, and even then the cost and the time needed for the Caterpillar test would rule out its use for production batch testing. Since production was expected to consist largely of the heavy-duty types of additive, it appeared that the ideal test unit would be a small well-made quantity produced diesel engine, which could be obtained relatively cheaply, and for which spares must be readily available. As a result a number of "Cub Diesel Mark III" generator sets were obtained, and these, after minor modifications to the engines and a re-design of the cooling system, gave good service until they were eventually replaced by the AV1.

The Cub engines were horizontally-opposed twin-cylinder units of 80 mm bore by 100 mm stroke and were fitted with detachable wet liners. They suffered from the disadvantage that, owing to their aluminium construction, their joint faces were liable to damage and were difficult to keep oil tight; moreover, special precautions were necessary to keep down crankcase dilution owing to the arrangement of fuel pumps and injectors internally in the crankcase. The engines did, however, give consistent and satisfactory results, provided all the necessary precautions were taken. When Associated British Oil Engines were in the process of introducing the Petters

AV1 engine, with the same type of combustion chamber as the Cub, but of much more robust cast iron construction and with external fuel pump, opportunity was taken to try out one of the prototype units for oil test purposes. Experience over some months with this unit confirmed its advantages, and subsequently six further units were put into operation. Subsequent co-operation with the manufacturers has resulted in the development of what is now for many purposes a satisfactory oil test engine.

The advantages claimed for the unit are :—

(1) low initial cost and batch operation at considerably less total expense than for the operation of one Caterpillar unit;

(2) the unit is responsive to changes in the fuel and lubricating oil, but within reasonable limits is insensitive to small changes in most of the test conditions;

(3) provided the usual precautions are taken, consistent results are easily obtainable and have lined up very well with general service experience;

(4) basically the engine is a production unit and, although now superseded in large-scale production by the direct-injection version, the manufacturers have co-operated and supply the air-cell type of engine as a " laboratory oil test engine " to special order; spares are readily and cheaply available;

(5) the only specialized components required for test purposes are pistons and rings, which are produced in batches to accurate dimensions, and held in stock by the manufacturers;

(6) low running costs and, by adopting the test procedure discussed, the possibility of evaluating many of the most important characteristics of a crankcase oil in 120 hours running time, *i.e.*, in considerably less than a week if running is continuous;

(7) the unit is available both with air-cell type of combustion chamber and with direct-injection combustion equipment, and is convertible without undue modification; consequently the influence of combustion characteristics on fuels and oils can be studied.

On the debit side, as with all small diesels, the unit is sensitive to cleanliness of the fuel and injection equipment, and in addition the life of such components as crankshaft, fuel pump operating gear, and bearings is, in term of hours of operation, lower than that of the Caterpillar unit.

It is not claimed that the AV1 unit can replace the Caterpillar unit for official tests, but rather that it is extremely suitable for batch testing of both base oils and additives, and also for general comparison purposes between different oils. Further, it does give a quick means of sorting out those oils which are likely to pass the Caterpillar series of tests from those which will definitely fail, but, owing to the somewhat indefinite requirements of the DEF/2101 and MIL-0-2104 pass standards (which depend upon more than one evaluation factor and include positioning of deposits as well as their magnitude), no other engine can ever conclusively determine the acceptability or not of borderline oils. Such oils therefore can only be evaluated on the Caterpillar unit itself. The AV1 unit, however, does enable the additive concentrations required for satisfactory pass standards with differ-

ent base oils to be quickly and easily determined with a good degree of reliability, and this allows a valuable saving in testing time and costs.

Description of Engine

The correct designation of the engine used for oil test purposes is the " Petters AV1 Laboratory Oil Test Engine," and it is obtainable from Petters Ltd. of Staines. This engine is derived from the original AV1 Series I, Mark II engine, which was in quantity production until superseded by the direct-injection Series II type.

The following are the main particulars of the engine for oil test purposes :—

Number of cylinders	1
Bore	80 mm (3·15 inches)
Stroke	110 mm (4·33 inches)
Swept vol	553 cc (33·73 cu. in.)
Clearance between piston and cylinder head	0·038–0·040 inch
Compression ratio	19 : 1 nominal
Rated power	5 b.h.p. at 1500 r.p.m.
Compression pressure	685 p.s.i.
Maximum pressure	1065 p.s.i. approx.
Fuel injection pressure	2625 p.s.i.
Capacity of oil sump	5 pints
Injection spill timing	21° to 22° BTC

Fig 1 shows an exploded view of the engine, from which it will be seen that a separate cylinder block is mounted on a substantial cast iron crankcase and held down by four $\frac{5}{8}$-inch dia studs. A detachable wet liner is retained in this block by a counterbore at the top and a single neoprene sealing ring at the bottom. This liner is of heavy construction with a uniform wall thickness of 0·316-inch so that distortion due to mechanical and thermal stresses is minimized. The cylinder head is held down by four $\frac{5}{8}$-inch studs and a copper–asbestos joint washer is employed. Brass distance washers of various thicknesses are provided for use between the cylinder block and crankcase to enable the piston crown to cylinder head clearance to be maintained at 0·038 to 0·040-inch for each build. Valve gear operation is of conventional type, and is by push rods. The crankshaft is of rigid construction, and has two bolted-on balance weights, while main bearings are one-piece thin-shell bushes and are white-metal coated. Big-end bearings are also of the thin-shell type, and consist of a lead flash coated copper–lead (70/30) top half and white-metal lower half. The camshaft is driven by spur gears from the front end of the crankshaft, and mechanism carried by the gear on the camshaft operates the governor.

A plunger type oil pump is operated from an eccentric on the crankshaft and feeds oil directly through the crankshaft to the big-end and by internal oil pipes to each main bearing. Oil pressure is controlled by a ball relief valve, and external oil pipes lead from this valve to the rocker gear. Later engines are fitted with a larger oil pump, but it is not believed that this modification makes any difference to the test results.

The combustion chamber design is of the air-cell type with the top half of the air-cell removable for inspection. Fuel injection timing is set by modifying the clearance between the pump operating rocker and the camshaft.

The unit can be converted to the direct-injection type by changing over the cylinder block, cylinder head, piston, camshaft, and injector.

Modifications to Standard

It is recommended that the following modifications be carried out to the engine as supplied :—

(1) Paint the inside of the crankcase to prevent bearings and pistons being scored by sand working out of the castings.

(2) Replace the push-in type of dipstick by a screw-in one to prevent slight oil weepage.

(3) Countersink the valve guides at each end at an angle of 45° with a $\frac{3}{8}$-inch drill to minimize valve sticking on certain oil and fuel combinations.

(4) Drill the crankcase to take a connexion to an oil-circulating pump and its return and also to take a bulb for an oil temperature controlling thermometer. The positioning of these can be seen by reference to Figs 1, 2, and 3.

(5) Provide an auxiliary drive for an oil-circulating pump, needed for the oil temperature control circuit, by the addition of an extension shaft to the half speed drive at the gear end.

(6) Fit 50 per cent stronger than standard inner and outer valve springs.

(7) If testing is to be carried out on a variety of oils fit little-end bushes in Admiralty gun-metal.

(8) Replace the standard neoprene liner sealing ring with the Cub sealing ring (Part No. T.100) of greater cross-sectional area. Chamfer the cylinder block to prevent cutting of this larger ring and lightly smear with lanoline to assist assembly.

(9) Pistons and rings used for oil test purposes are manufactured by Messrs Hepworth & Grandage Ltd. to special tolerances. Three compression rings, of which the lower two are taper turned, and a slotted scraper ring are fitted; the upper scraper ring groove is left free. For each test a new piston and set of rings are required.

(10) Replace the rocker box breather valve with a 1-inch union for connexion to a blow-by meter.

Auxiliary Circuits

(a) *Coolant*

A vane type coolant pump, capacity 240 gal/hr, supplies kerosine via a heat exchanger to the cylinder head, whence the coolant flows through the head and cylinder block back to the header tank. A coolant flowmeter is arranged in the return line, and a Cambridge dial thermometer regulator mounted in the outlet from the cylinder block energizes a magnetic valve arranged to control the amount of cooling water flowing through the heat exhanger, fine control being achieved by arranging this magnetic valve in a by-pass circuit (Fig 4).

(b) *Oil*

Oil temperature is controlled by circulating the oil through an external circuit by means of a Suddo No. 0 pump, belt driven at half engine speed from the extension shaft. A small heat exchanger is situated on the outlet side of the pump, and delivery is directly back to the crankcase. Control is by means of a Cambridge dial thermometer regulator the bulb of which is immersed in the crank-case oil and which energizes a magnetic valve controlling the amount of cooling water flowing through the heat exchanger, a by-pass circuit again being employed for fine control (Fig 3).

(c) *Loading*

Heenan & Froude DPX.1 hydraulic dynamometers and calibrated electrical generators have both proved satisfactory. Fig 2 illustrates the layout of AV1 test beds at our laboratories.

(d) *Instrumentation*

In addition to the controlling thermometer regulators, copper–constantan thermocouples are inserted immediately adjacent to the coolant inlet and outlet connexions, and a chromel–alumel thermocouple is mounted in the exhaust manifold 2 inches away from the face of the cylinder head. All thermocouples are connected to multipoint recorders. An oil pressure gauge and a tachometer are also required, while pressure cut out switches are arranged to cut off the fuel supply to the engine should the oil pressure fall below 5 p.s.i. or the coolant flow below 200 gal/hr. Fig 5 shows a typical control panel for a pair of engines.

(e) *Exhaust System*

Galvanized steel pipe, $1\frac{1}{2}$ inches dia, is used throughout, and the distance between the engine port and the expansion chamber is standardized at 16 ft. Expansion boxes are standardized at 4 ft long by 5 inches diameter, and the gas flow through the box is at right angles to that through the main exhaust system (Fig 6). Tail pipes up to 30 ft have proved satisfactory, but exhaust pipes common to more than one engine are not used.

Preparation of Engine

(a) *Pistons and Rings*

A new piston and set of rings are fitted for each test. Top compression rings are prepared by holding them in a special holder and lapping down both top and bottom faces on a hard wooden block using No. 320 carborundum powder to give side clearances when assembled in the test piston of as near 0·002 inch as possible. Slotted scraper rings are similarly lapped down to give as near 0·003 inch side clearance as possible. The taper-turned compression rings are lapped on the lower face only. The top compression and scraper rings are now lapped on the periphery in a liner kept specially for the purpose, and finally all ring gaps are set to 0·014 to 0·016 inch in a jig. The second and third compression rings are very lightly lapped on the periphery to remove any slight burrs, but not sufficient to remove the taper,

it being essential that no burrs are left on the edges of the rings, otherwise abnormal wear will occur.

Special care must also be taken when handling the piston to make sure that no burrs are formed on the edges of the ring grooves, and before final assembly on the engine a 0·002-inch feeler gauge must be run round the piston between the upper and lower faces of each compression ring and groove, and a 0·003-inch feeler gauge round the scraper ring groove.

All compression rings are chemically cleaned and weighed before and after each test.

Gudgeon pins last an average of approximately eight tests.

(b) *Liner*

The number of tests a liner will complete before rejection depends upon both the oils tested and the fuel used, and is between the extremes of three, for high sulphur fuels with straight base oils, and ten, for low sulphur fuels and highly compounded oils. Liners are rejected when the maximum wear exceeds 0·003 inch or when the ovality exceeds 0·0015 inch. They are measured before and after each test across two diameters at right angles, in three positions axially.

(c) *Bearings*

No measurements are taken, but connecting rod bearings are rejected when the lead plating has worn through, the average life of a bearing before replacement being eight tests. Main bearings are examined for signs of fatigue failure at intervals of eight tests. Crankshafts are replaced when crankpin ovality exceeds 0·003 inch, the useful life before replacement averages thirty tests. Crankshafts may be reground for further use, and 0·010 and 0·020 inch undersize main bearings and 0·010 inch undersize connecting rod bearings are available.

(d) *Connecting Rods*

Connecting rods and pistons are checked before every test for truth in a connecting rod aligning gauge, and connecting rods are straightened if the " out of truth " exceeds 0·001 inch. Faulty alignment may lead to excessive oil consumption.

(e) *Crankcase*

Before each test the crankcase and components are thoroughly cleaned with white spirit, or with " Cellosolve " if there is an exceptional amount of lacquer.

(f) *Cylinder Head*

The cylinder head is decarbonized and the valves ground in after each test. Cylinder heads are rejected when the valves appear excessively pocketed, but their life averages approximately thirty tests. Refacing the head to eliminate pocketing is not recommended, owing to the thin metal section, but cylinder heads may be reclaimed by fitting valve inserts.

Test Procedure for Determining the Effect of Engine Oils on Ring Sticking, Wear, and the Accumulation of Deposits at High Temperature

A standard test procedure designated AT/4 and detailed in Table I has been adopted for evaluating oils at high temperature. Although general practice is to run the engines continuously throughout the 120-hour test period (with the exception of a 15-minute stop every 6 hours for oil check and if necessary addition the of fresh oil), tests have indicated that stopping the

Table I

Standard High Temperature Test Procedure AT/4

Coolant	Kerosine
R.p.m.	1500
B.h.p.	4·9
B.m.e.p., p.s.i.	77
Sump oil temperature, ° C	55
Rate of coolant flow, gal/hr	240 ± 10
Coolant outlet temperature from cylinder block, ° C	85
Coolant inlet temperature to cylinder head, ° C	78 ± 2
Oil pressure, p.s.i.	6 min
Test duration, hr	120
Oil change periods	No change during test
Fuel spill timing	21° to 22° BTDC

engine overnight or over the week-end does not significantly influence the results, except towards the end of tests on those straight oils which are prone to give early ring sticking. In such cases difficulty may be encountered in restarting after a prolonged shut-down, making the completion of the full 120-hour period impossible; alternatively, there may be some difference in the degree of ring sticking as compared with a test with no prolonged shut-down.

Before commencing the test proper, the crankcase is filled to the high level mark on the dipstick with the test oil (6½ pints required for the complete oil circuit shown). Running-in is completed to the schedule given in Table II, the oil is then drained out, left 15 minutes to drain, and the crank-

Table II

AT/4 Procedure—Running-in Conditions

Duration hr	Load, b.h.p.	Jacket outlet temp, ° C	R.p.m.	Sump oil temp, ° C
2	1·5	50	1500	55 max
2	3·0	60	1500	55 max
3	4·0	75	1500	55 max
1	4·9	75–80	1500	55 max

case finally emptied by means of a syringe. The oil system is then recharged to the top level of the dipstick with fresh test oil. At each 6-hourly oil check, provided the level has fallen at least ½ pint, sufficient oil is added

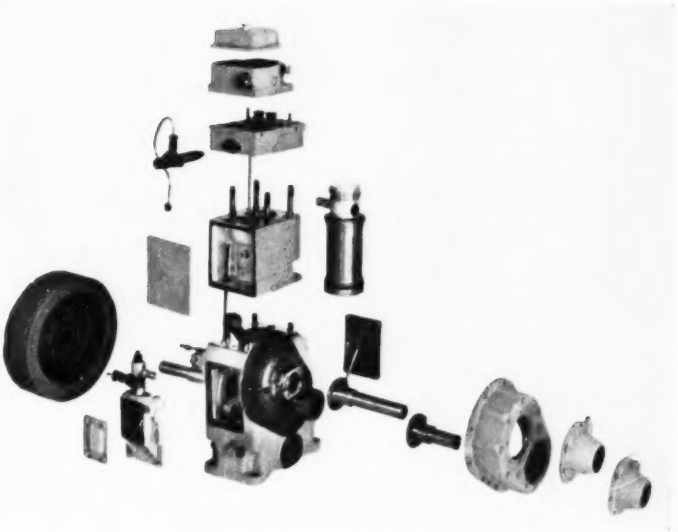


FIG 1

EXPLODED VIEW OF AVI ENGINE SHOWING MAJOR COMPONENTS

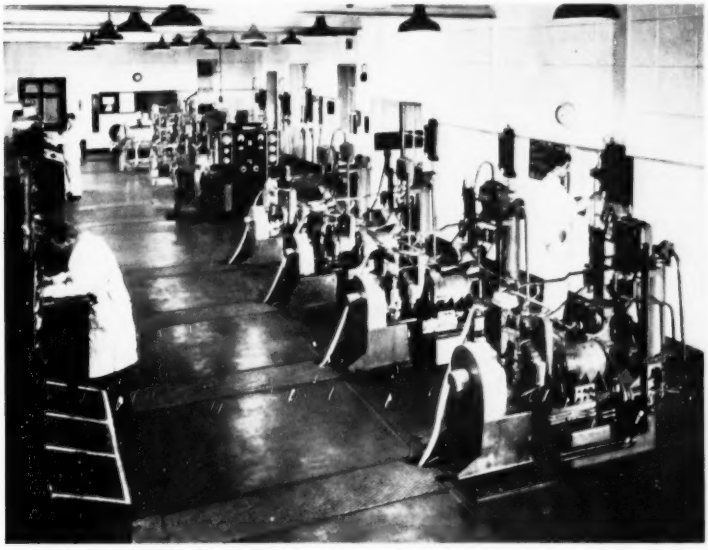


FIG 2

GENERAL VIEW OF AVI TEST ENGINES

[*To face p. 588.*

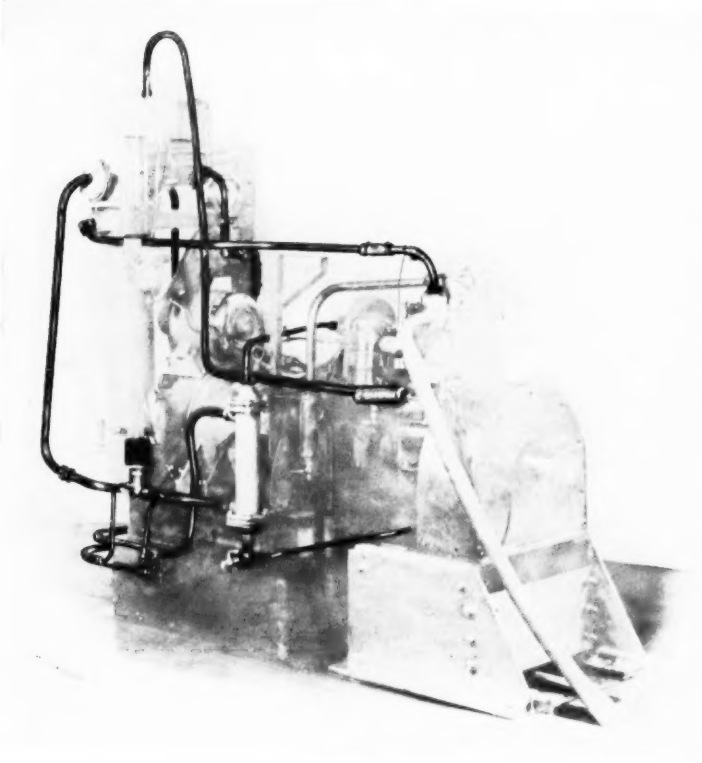


FIG 3

LAYOUT OF COOLANT AND OIL SYSTEMS, AVI TEST ENGINE

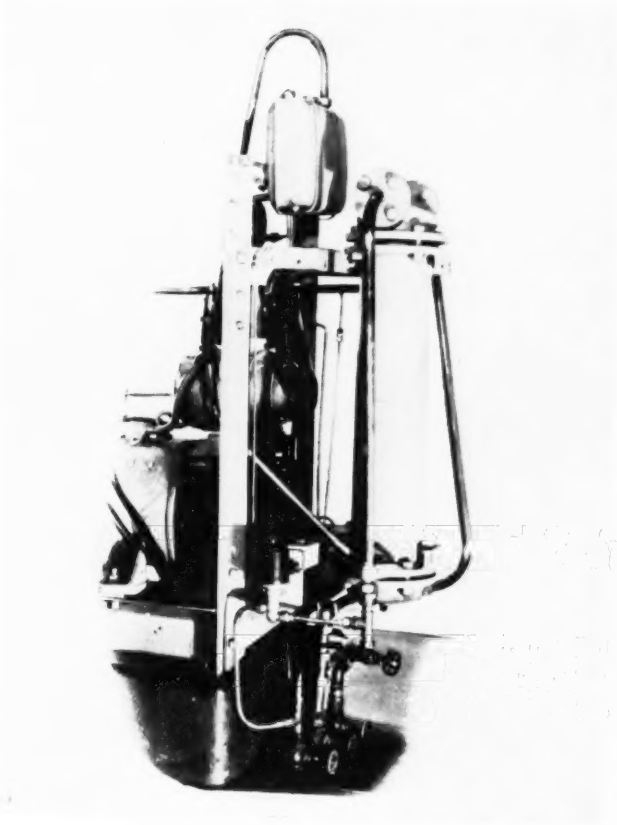


FIG 4

ARRANGEMENT OF COOLANT TEMPERATURE CONTROL

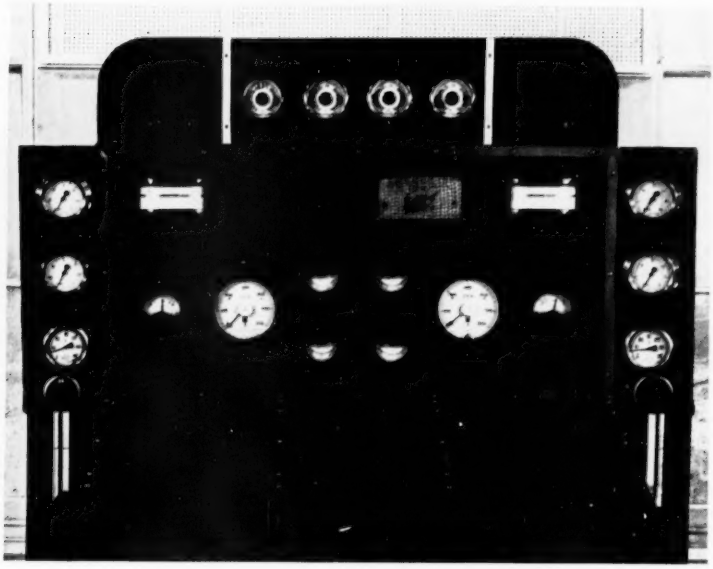


FIG 5
CONTROL PANEL FOR AV1 TEST ENGINE

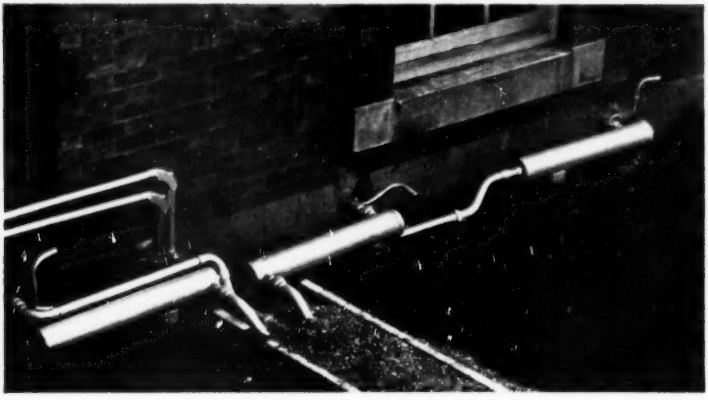
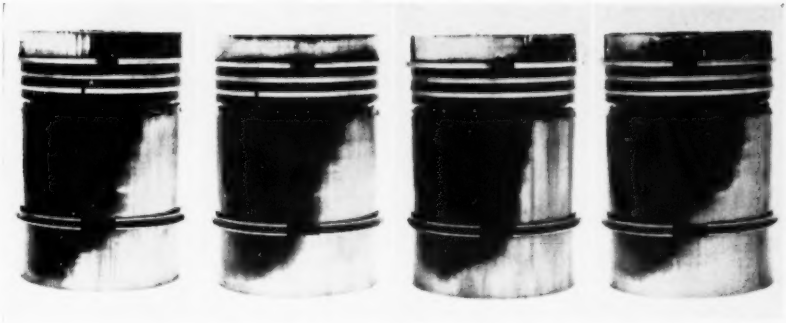
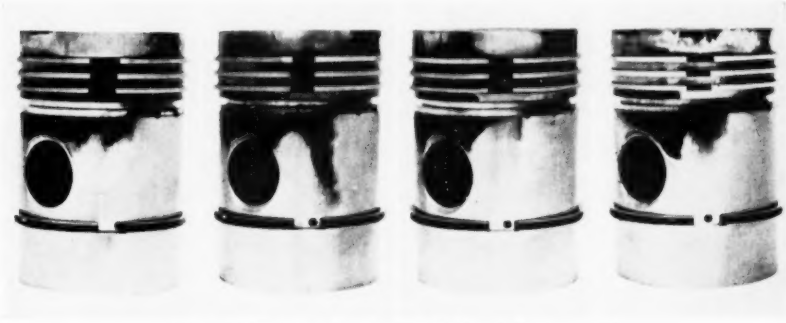


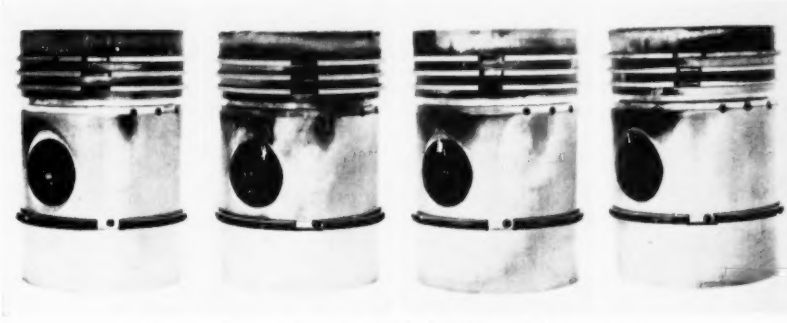
FIG 6
ARRANGEMENT OF EXHAUST SYSTEM, AV1 TEST ENGINE



(*a*) Regular grade oil; fuel, 0·25% sulphur content



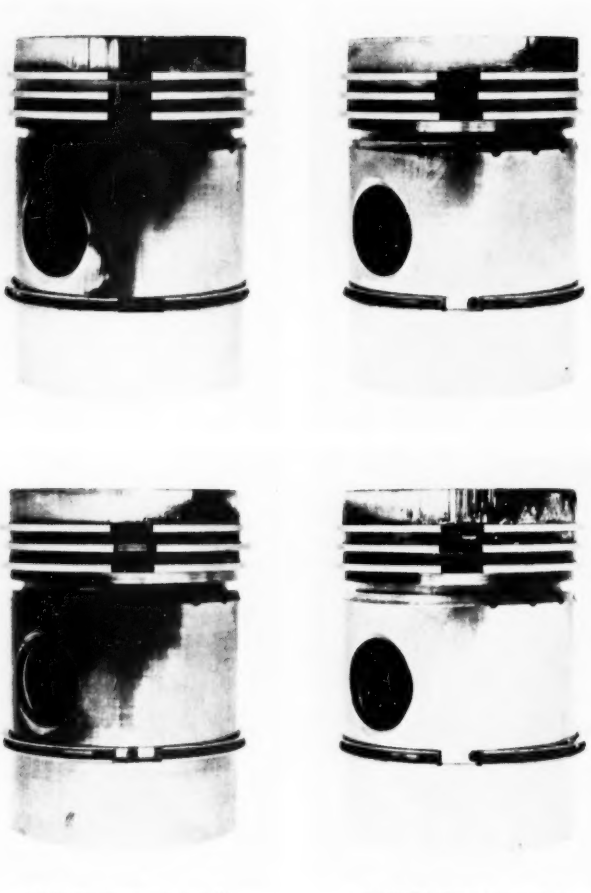
(*b*) 2-104B type oil; fuel, 0·25% sulphur content



(*c*) Supplement 1 type oil; fuel, 1·0% sulphur content

FIG 7

AVI PISTONS AFTER 120-HOUR TEST. TYPICAL RESULTS ON REGULAR, 2-104B AND SUPPLEMENT 1 TYPE OILS

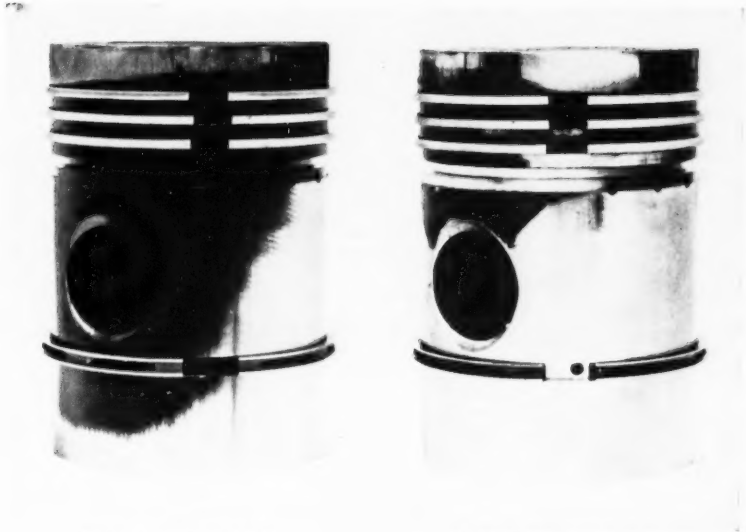


SAE 30 Base oil " A " SAE 30 Base oil " B "

FIG 8

AV1 PISTONS AFTER 120-HOUR TEST. BASE OIL EFFECTS ON ADDITIVE-TREATED OILS

Fuel, 0·25% sulphur content gas oil; identical 2-104B type additive treatment for both oils.



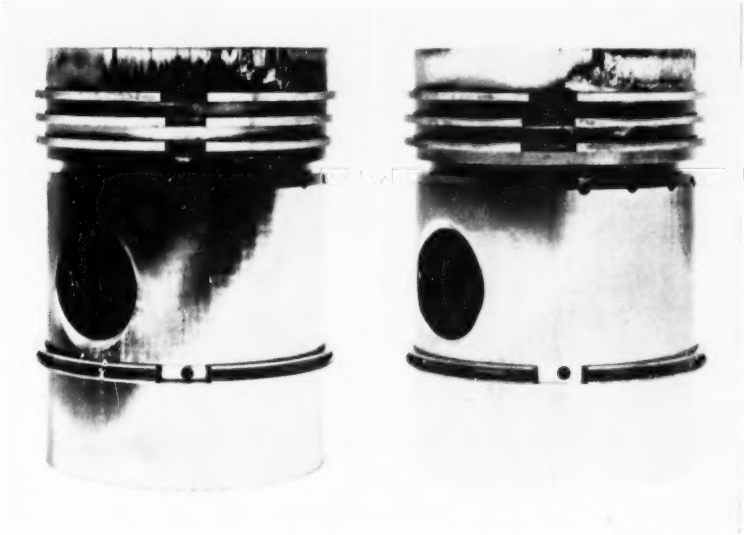
SAE 30 Base oil " C "

SAE 30 Base oil " D "

FIG 9

AV1 PISTONS AFTER 120-HOUR TEST. BASE OIL EFFECTS ON ADDITIVE-TREATED OILS

Fuel, 0·25% sulphur content gas oil; identical 2-104B type additive treatment for both oils.



SAE 50 Base oil " E "
6% additive " D "

SAE 50 Base oil " F "
5% additive " D "

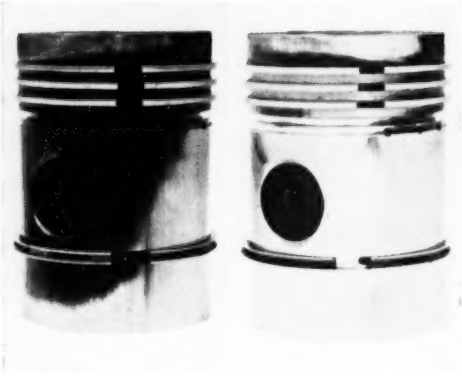
FIG 10

AV1 PISTONS AFTER 120-HOUR TEST. BASE OIL EFFECTS ON ADDITIVE-TREATED OILS

Fuel, 0·45% sulphur content gas oil.

Additive " A "

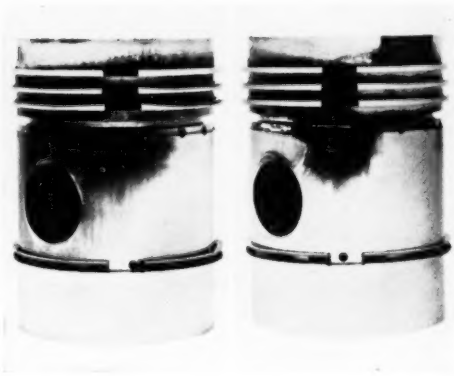
4% 6%



(*a*) Base oil No. 1; 0·25% sulphur content fuel

Additive " D "

5% 6%



(*b*) Base oil No. 2; 0·45% sulphur content fuel

Additive " D "

4·5% 5·25%

(*c*) Base oil No. 5; 0·45% sulphur content fuel

Additive " D "

4·5% 5·25%

(*d*) Base oil No. 6; 0·45% sulphur content fuel

FIG 14

AVI PISTONS AFTER 120-HOUR TEST. ADDITIVE RESPONSE

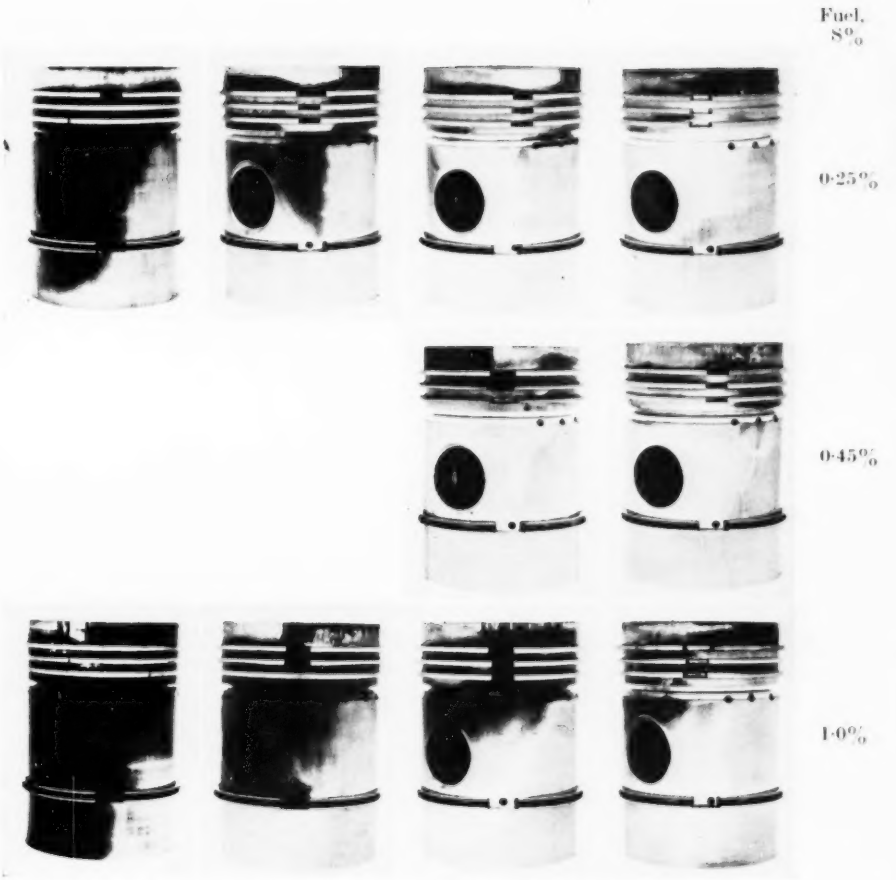
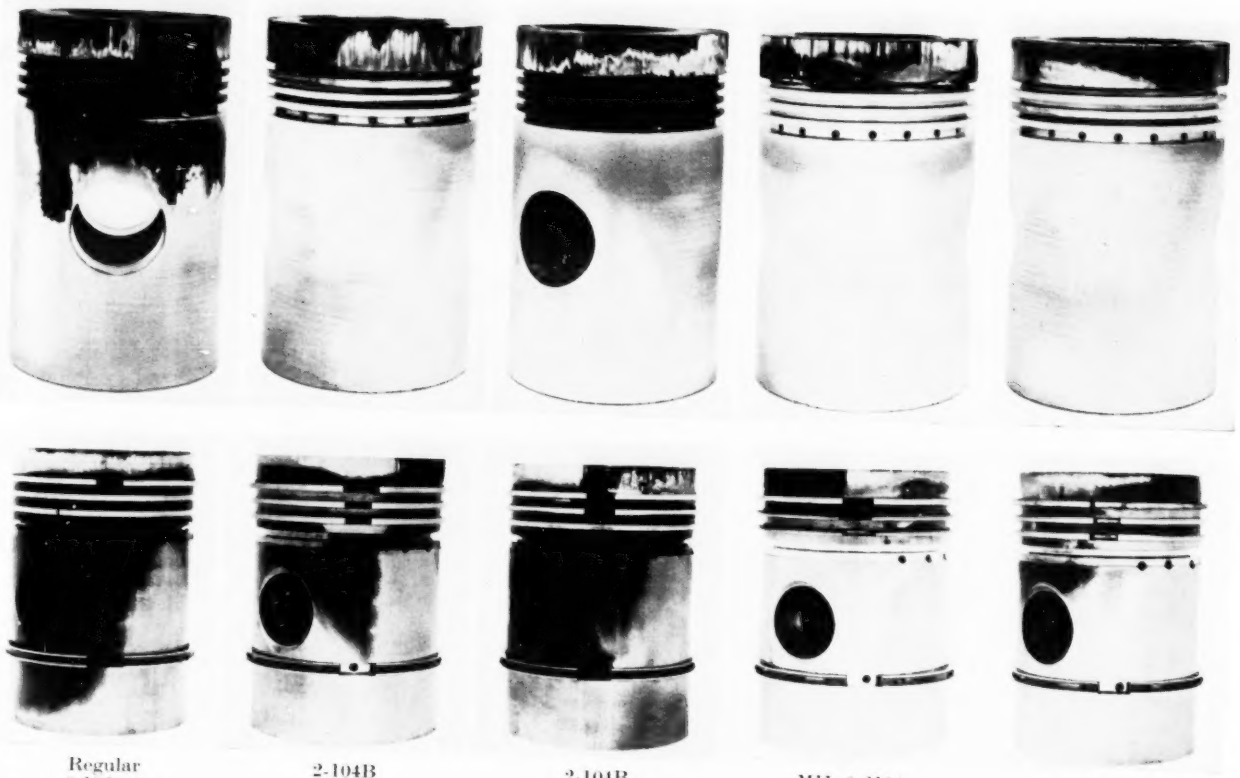


Fig 23

AVI PISTONS AFTER 120-HOUR TEST. AVERAGE RESULTS ON VARIOUS TYPES OF OILS AND FUELS



Oil :	Regular	2-104B	2-104B	MIL-0-2104	Supplement 1
Fuel :	0·19% S	0·19% S	1·0% S	0·45% S	1·0% S

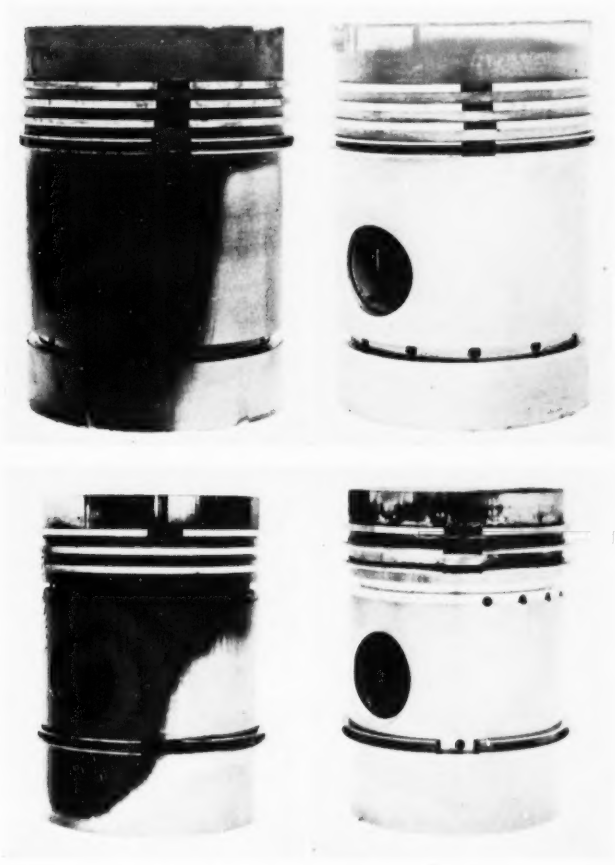
FIG 27

COMPARATIVE CATERPILLAR AND AV1 PISTON RESULTS WITH DIFFERENT OILS AND FUELS

A	B
Straight oil	Supplement 1 oil

Pistons from 9·6-litre AEC double-decker buses after 100,000 miles.

[pistons cleaned and re-ringed every 25,000 miles]	[no re-ringing or cleaning of pistons]



Pistons from AVI laboratory tests

FIG 32

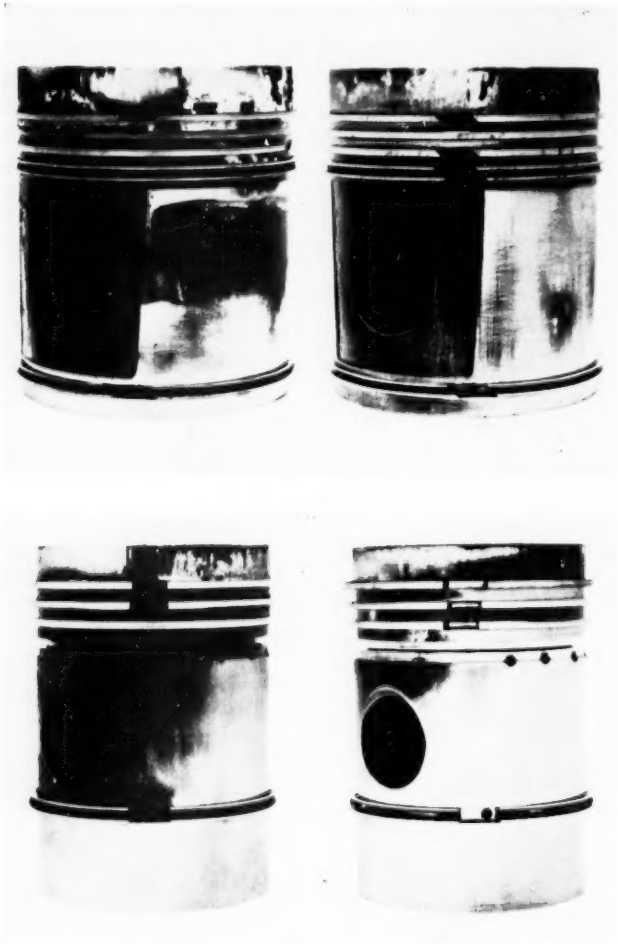
COMPARISON OF PISTONS FROM AEC 9·6-LITRE ENGINES AND FROM AVI TESTS

Fuel, sulphur content average 0·7%.

A
2-104B oil

B
Supplement 1 oil

Pistons from Davey–Paxman power house engine after 450 hours



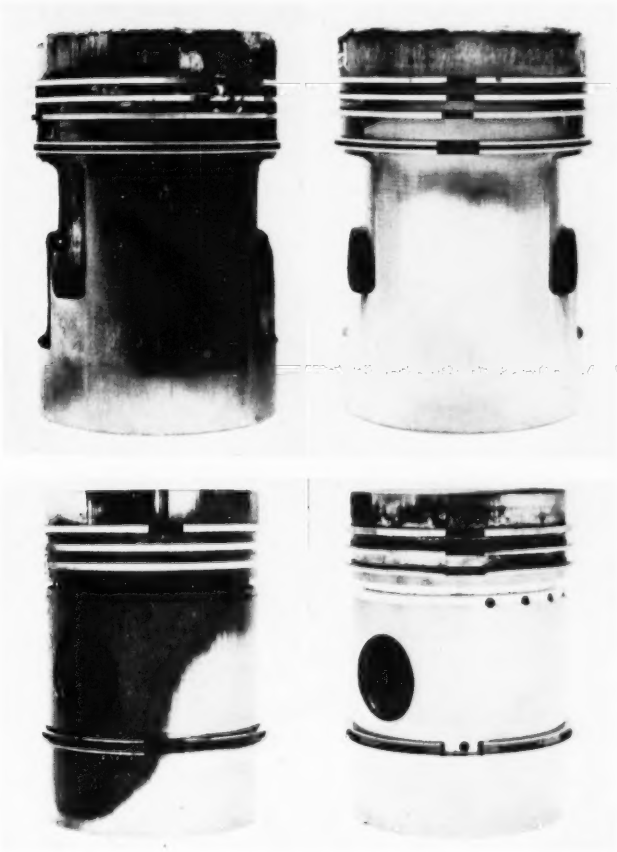
Pistons from AV1 laboratory tests

FIG 33

COMPARISON OF PISTONS FROM DAVEY–PAXMAN ENGINE AND FROM AV1 TESTS

Fuel, sulphur content 1%.

A	B
Straight oil	Supplement I oil
Pistons from 8-cyl power house engines	
After 214 hours	After 1270 hours



Pistons from AVI laboratory tests

FIG 34

COMPARISON OF PISTONS FROM 8-CYL POWER HOUSE ENGINE AND FROM AVI TESTS

Fuel, sulphur content average 0·7%.

A

Straight oil

After 205 hours

B

MIL-0-2104 oil

Pistons from single-cylinder two-stroke diesel tractor

After 2000 hours

C

Supplement 1 oil

After 1750 hours

Pistons from AV1 laboratory tests

FIG 35

COMPARISON OF PISTONS FROM DIESEL TRACTOR AND FROM AV1 TESTS

Fuel, sulphur content average 0·7%

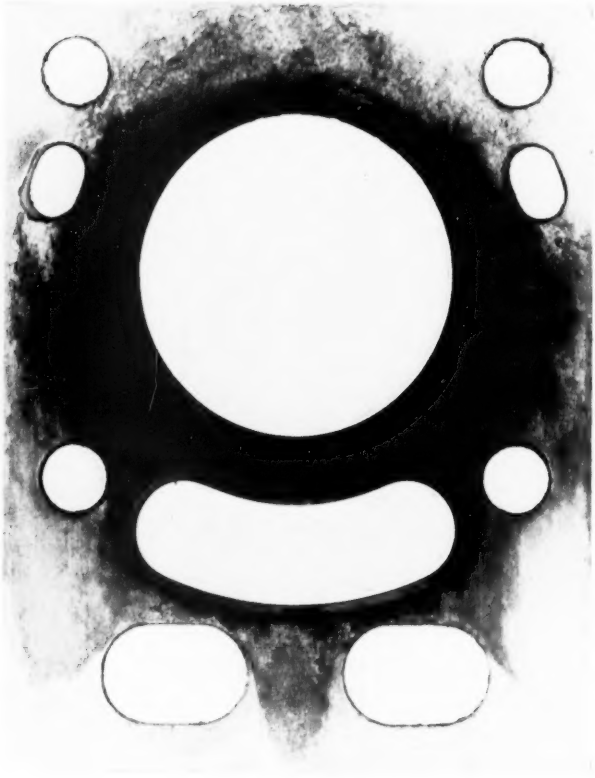


FIG 43

TYPICAL CYLINDER HEAD GASKET AFTER USE

to bring the oil level to the maximum mark. All oil into and out of the crankcase is weighed.

Checks for coolant and fuel dilution of the test oil are made at completion of running-in and at the end of the test.

Fuel consumption, temperature, and load conditions are recorded every 15 minutes and if, after run-in, the fuel consumption rises above 2·45 pints/hr with an SAE 30 oil (2·30 pints/hr SAE 5W and 10W and 2·60 SAE 50) the injector is removed for servicing. Fuel consumptions are heaviest during the latter part of the run-in immediately after fitting a new liner. Incorrect injection timing, worn camshaft bushes, worn pump operating rocker, or excessive pocketing of the valves may also cause high fuel consumption.

Evaluation of Results

For all work such as general comparison between base oils and comparison between oils treated with additives to different quality levels, the following relatively simple evaluation has proved perfectly satisfactory—the only major modification to the rating scale over a number of years being the substitution of piston land lacquer * rating for cylinder liner deposit rating. Liner deposit ratings were found to be substantially constant for different treated oils, although showing a reasonable divergence between treated and untreated oils. When the engine is used to predict L.1 performance for MIL-0-2104 or DEF.2101 requirement the same method of rating is used, but particular attention is paid not only to the complete absence of ring sticking but also to the piston skirt * and land lacquer deposits. When batch testing additives particular attention is paid to the same items.

(a) *Piston Ring Sticking*

Obtain the merit rating for each of the three compression rings, according to Table III, and take the average.

Table III

Nomenclature	Merit rating
Free ring	10
Sluggish ring	9
Stuck ring	7 for ring stuck 0–45°, subtract 1 for every further complete 45° of sticking.

Multiply average rating by weight factor of 3·5

$\therefore$ Maximum possible ring sticking rating $= 3{\cdot}5 \times 10 = 35$

(b) *Piston Skirt Lacquer Deposits*

Remove the piston from the engine and wipe lightly to remove oil but not sludge. Obtain overall demerit rating from 0 to 10, according to percentage

* Throughout the paper the terms " piston skirt " and " piston land " lacquer are used to denote all deposits on these components not easily removed by kerosine wash. Such terms, therefore, include other deposits than those of brown varnish-like nature, and are more akin to the U.S. Navy definitions.

area covered; modify this by multiplying by the appropriate colour factor in Table IV. The piston skirt is then wiped with a rag soaked in kerosine and again rated as above. The latter rating, multiplied by a weight factor

TABLE IV

Discoloration of parts	Colour factor
Clean	0·0
Light brown	0·25
Brown	0·50
Dark brown	0·75
Black	1·00

of 3·0 and subtracted from 30, represents the piston skirt lacquer merit rating. The difference between first and second demerit ratings, again multiplied by 3·0 and subtracted from 30, gives the piston skirt sludge merit rating.

Piston skirt lacquer ratings are used in the final total merit figure for the test, but piston skirt sludge ratings are not part of this, and are reported separately.

$\therefore$ Maximum possible piston skirt lacquer rating $= 3{\cdot}0 \times 10 = 30$

(c) *General Component Deposits*

Obtain the demerit rating from 0 to 10 of each component according to percentage area covered, modify by multiplying by the appropriate thickness factor in Table V, and subtract from 10 to obtain the merit rating.

TABLE V

Type of sludge	Thickness factor
None	0·0
Light	0·25
Moderate	0·50
Moderately heavy	0·75
Heavy	1·00

The components are : (i) push rod cover plate; (ii) rocker arm cover plate; (iii) oil screeen; (iv) inside the piston.

Take the mean of the merit values so obtained and multiply by a weight factor of 1·0.

$\therefore$ Maximum possible general components deposit rating $= 1 \times 10 = 10$

(d) *Scraper Ring Deposits*

Obtain a demerit rating from 0 to 10, according to percentage area covered between upper and lower scraping faces of the rings, and subtract from 10 to obtain the merit rating.

Multiply this merit rating by a weight factor of 1·0

$\therefore$ Maximum possible scraper ring deposit rating $= 1 \times 10 = 10$

Land Lacquer Deposits

For each land obtain a demerit rating from 0 to 10, according to percentage area of periphery of the land covered with lacquer. Modify this by multiplying by appropriate colour factor in Table IV and subtract from 10 to obtain the merit rating. The mean value of the three piston lands is taken as the land lacquer merit rating.

Multiply this merit rating by weight factor of 1·0

$\therefore$ Maximum possible land lacquer rating $= 1 \times 10 = 10$

(f) *Piston Crown Land Cutting*

Obtain a demerit rating from 0 to 10, according to percentage area cut, modify by multiplying by the depth factor in Table VI, and subtract from 10 to obtain the merit rating.

TABLE VI

Depth	Depth factor
Light	0·50
Moderate	0·75
Deep	1·00

Multiply this merit rating by a weight factor of 0·5

$\therefore$ Maximum possible piston crown land cutting rating $= 0{\cdot}5 \times 10 = 5$

(g) *Total Merit Rating*

The total merit rating is therefore the sum of items (*a*) to (*f*)

$\therefore$ Maximum possible total rating $= 35 + 30 + 10 + 10 + 10 + 5 = 100$

(h) *Top Ring Groove Carbon Deposits*

In addition, consideration is given to the top ring groove carbon deposits which are entered separately and assessed as follows :—

Obtain a demerit rating 0 to 10, according to percentage area of the periphery of the groove behind the ring that is covered with carbon. Modify this by multiplying by appropriate depth factor in Table VI and subtract from 10 to obtain the merit rating.

Top ring groove deposits show less consistency from test to test than some items, and investigation is still proceeding to determine the reason.

INITIAL DEVELOPMENT WORK

Initial testing was of an exploratory character, with the object of developing a high temperature moderate-output procedure which would serve as a test for approving production batches of additives, and would in addition correlate to some degree with the AXS-1551 procedure and with service experience. It was considered essential that the test should be of shorter duration than the 480 hours AXS-1551 test, and one obvious method of accomplishing this would have been to run at a high b.m.e.p. This was

rejected because it has the drawback of shortening engine life, and usually means running above the smoke limit of the engine. The possibility of using coolants with heat transfer and thermal conductivity characteristics lower than water was therefore considered, the object being to raise the piston temperature without the necessity of running at an unduly high b.m.e.p.

Various coolants were tried, some of which were unduly severe. Eventually kerosine was selected and enabled a 120-hr test procedure to be adopted at a moderate b.m.e.p. of approximately 77 with a coolant outlet temperature of 85° C. Thus, it was possible to obtain ring sticking with untreated base oils at the end of this period, even when using a low (0·25 per cent) sulphur fuel. It was also found that base oils, when tested under these conditions, gave considerable lacquer and sludge deposits, whereas additive treated oils, apart from eliminating ring sticking, considerably reduced the lacquer and sludge deposits.

It is emphasized that the use of kerosine is an essential part of the test procedure, and it is felt that the conditions produced by its use are not too far away from the more severe practical conditions, but are not so severe as to cause " cracking " of some of the base oils and additives currently used, and thereby produce conditions which might be artificial for oil–additive combinations used for less arduous work.

Glycol was one of the coolants tried, but it was found that any dilution of the oil by this coolant could upset a test, since it acts as a flocculating agent and precipitates solids from the oil. By comparison kerosine has no such effect, and dilutions of even 3 per cent can be tolerated without influencing the results. It is also relatively easy to check for combined kerosine and diesel fuel dilution by steam distillation.

In view of the higher temperatures associated with the use of kerosine as a coolant reversed flow cooling was adopted (*i.e.*, the cylinder head was made the inlet and the cylinder block the outlet) in order to keep injectors as cool as possible and hence reduce the incidence of injector trouble.

Certain minor difficulties were encountered during the development stages of the procedure, and details are given in the section dealing with engine modifications.

Tests with fuels of varying sulphur content revealed that the engine was sensitive to fuels, and it was therefore decided to adopt the same technique as used in the L.1 procedure when testing oils of different performance levels, namely to employ lower grade fuels when testing oils of superior performance level rather than alter the test conditions.

As a result regular, premium, and 2-104B; MIL-0-2104 and DEF/2101; and Supplement I type oils are normally tested with fuels meeting the appropriate Caterpillar fuel specification.

In the case of Series 2 oils the approval test procedure is more severe and employs a supercharged Caterpillar test unit and the same fuel as for Supplement I tests. As yet no equivalent Petter AV1 test procedure had been adopted at our laboratories, although consideration is being given to supercharging an AV1 unit. At present the little Series 2 testing that has been carried out has been under the same conditions as for Supplement I type oils, but with a higher level of acceptance in so far as the test results are concerned.

Analysis of Results

(a) *Difference between Untreated and Treated Oils*

Tests were initially carried out on two grades of oil, a regular grade solvent extracted SAE 30 oil of 98 V.I., and oils treated to 2-104B standard by the addition of 4 per cent of additive " A," both series of tests being carried out on the 2-104B fuel using various engines and test beds. Regular grade oil consistently gave sticking of the second and third compression rings, leaving the top ring free with considerable scraper ring sludge and piston lacquer deposits, whereas the 2-104B type oils always produced free rings with absence of scraper ring sludge and less piston lacquer deposits.

Oils treated to Supplement I level by the addition of additive " B " and tested with 1·0 per cent sulphur fuel consistently produced free rings with absence of scraper ring sludge and a relatively clean piston.

Table VII shows some results from representative tests on the three grades of oils mentioned above, and it will be noted that the results shown are very consistent.

Table VII

Typical Merit Ratings on Various Oil Grades

Oil grade	Same regular oil				2-104B types				Supplement I types			
Reference fuel	2-104B				2-104B				Supplement I			
Crown cutting rating (max 5)	3·7	3·9	3·7	3·5	4·2	3·7	3·9	3·9	4·5	3·9	4·2	4·2
Piston ring sticking rating (max 35)	14·0	14·0	9·4	14·0	35·0	35·0	35·0	35·0	35·0	35·0	35·0	35·0
General components deposit rating (max 10)	7·6	6·6	7·1	7·3	8·5	8·8	7·8	8·5	8·7	9·1	8·5	8·8
Scraper ring sludge deposit rating (max 10)	1·0	1·4	2·6	0·8	10·0	10·0	10·0	10·0	10·0	10·0	10·0	10·0
Piston land lacquer deposit rating (max 10)	0·0	0·4	0·0	0·0	1·3	1·0	2·8	3·0	2·5	4·8	2·5	3·0
Piston skirt lacquer deposit rating (max 30)	17·5	14·8	16·4	16·8	27·2	26·5	28·2	28·5	26·2	28·0	25·5	27·5
Total merit rating (max 100)	43·8	41·1	39·2	42·4	86·2	85·0	87·7	88·9	86·9	90·8	85·7	88·5
Total deposit rating (max 60)	26·1	23·2	26·1	24·9	47·0	46·3	48·8	50·0	47·4	51·9	46·5	49·3

This table and Fig 7 indicates that the test procedure shows up with consistency the improvements obtained when the base oil is treated with additives.

(b) *Base Oil and Additive Response*

Initial tests having indicated the possibility of using the AT/4 test procedure for testing production batches of additives, it was considered desirable to know whether differences in base oils, when provided with the same additive treatment, could be detected. Table VIII shows results obtained from two tests on each of two SAE 30 base oils when given the identical 2-104B type additive treatment. Apart from the good repeatability obtained, it is noticeable that one oil gave consistently more lacquer on the piston skirt, and this is also evident from Fig 8.

Table IX and Fig 9 show further examples of how the procedure discriminates between two SAE 30 base oils having the same additive treatment and Table X and Fig 10 provide a similar comparison using different SAE 50 base oils.

TABLE VIII

Base Oil Effects on Additive Treated Oils. Fuel Used: 2-104B Reference Fuel

Additive Treatment: Identical 2-104B type treatment for both base oils

SAE 30 base oil	A		B	
	1st test	2nd test	1st test	2nd test
Crown cutting rating (max 5)	3·6	4·0	4·0	4·0
Piston ring sticking rating (max 35)	35·0	35·0	35·0	35·0
General components deposit rating (max 10)	8·0	8·4	8·6	8·7
Scraper ring sludge deposit rating (max 10)	10·0	10·0	10·0	10·0
Piston land lacquer deposit rating (max 10)	1·7	3·2	1·8	2·2
Piston skirt lacquer deposit rating (max 30)	23·5	23·6	28·6	29·2
Total merit rating (max 100)	81·8	84·2	88·0	89·1
Total deposit rating (max 60)	43·2	45·2	49·0	50·1

TABLE IX

Base Oil Effects on Additive Treated Oils. Fuel Used: 2-104B Reference Fuel

Additive Treatment: Identical 2-104B type treatment for both base oils

SAE 30 base oil	C	D
Crown cutting rating (max 5)	4·2	4·0
Piston ring sticking rating (max 35)	35·0	35·0
General components deposit rating (max 10)	8·5	8·6
Scraper ring sludge deposit rating (max 10)	10·0	10·0
Piston land lacquer deposit rating (max 10)	0·0	1·8
Piston skirt lacquer deposit rating (max 30)	16·1	27·3
Total merit rating (max 100)	73·8	86·7
Total deposit rating (max 60)	34·6	47·7

TABLE X

Base Oil Effects on Additive Treated Oils. Fuel Used: 2-104B Reference Fuel

SAE 50 base oil	E	F
Additive	6% D	5% D
Crown cutting rating (max 5)	4·5	3·7
Piston ring sticking rating (max 35)	35·0	35·0
General components deposit rating (max 10)	7·7	8·9
Scraper ring sludge deposit rating (max 10)	10·0	10·0
Piston land lacquer deposit rating (max 10)	2·5	3·6
Piston skirt lacquer deposit rating (max 30)	24·1	28·9
Total merit rating (max 100)	83·8	90·1
Total deposit rating (max 60)	44·3	51·4

Other examples of the ability of the test procedure to show up significant differences between base stocks are shown in Figs 11 and 12, where it will be noticed that a higher proportion of additive is usually required to bring SAE 50 oils up to MIL-0-2104 standard than is the case for SAE 30 oils, thus confirming AXS-1551 test results.

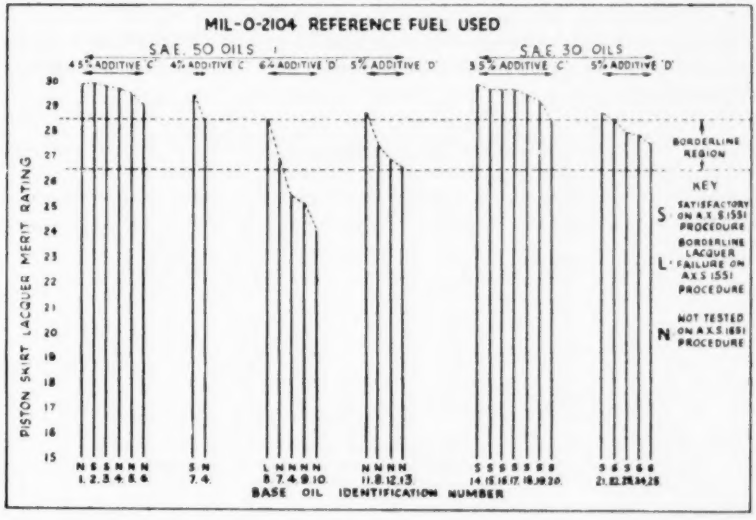


FIG 11

PETTER AV1 PISTON SKIRT LACQUER RATINGS FOR SAE 50 AND SAE 30 ADDITIVE TREATED OILS

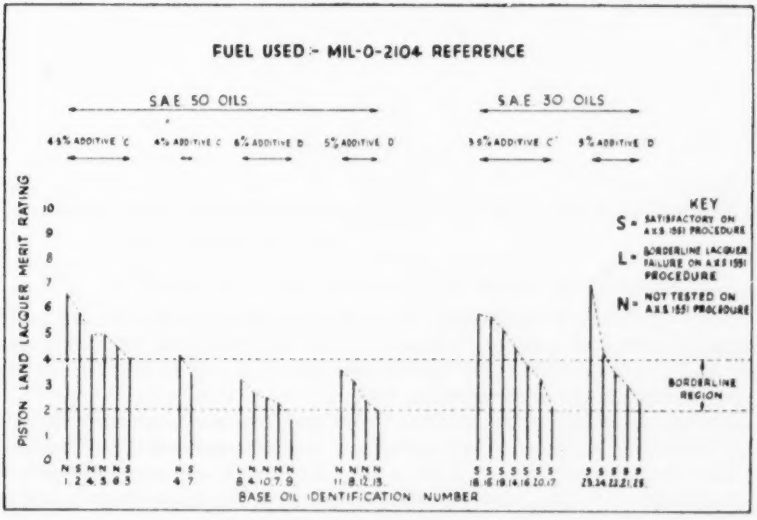

FUEL USED :- MIL-O-2104 REFERENCE
SAE 50 OILS
SAE 30 OILS
4.5% ADDITIVE 'C'
4% ADDITIVE 'C'
6% ADDITIVE 'D'
5% ADDITIVE 'D'
3.5% ADDITIVE 'C'
5% ADDITIVE 'D'
PISTON LAND LACQUER MERIT RATING
KEY
S = SATISFACTORY ON A.X.S 1551 PROCEDURE
L = BORDERLINE LACQUER FAILURE ON A.X.S 1551 PROCEDURE
N = NOT TESTED ON A.X.S 1551 PROCEDURE
BORDERLINE REGION
BASE OIL IDENTIFICATION NUMBER

FIG 12

PETTER AV1 PISTON LAND LACQUER MERIT RATINGS ON SAE 50 AND SAE 30 ADDITIVE TREATED OILS

The AT/4 test procedure will also indicate the response obtainable from a base oil containing increasing amounts of additive.

Examples of such tests are shown in Figs 13 and 14, from which is noticeable the progressive increase in cleanliness with increase in the additive concentration.

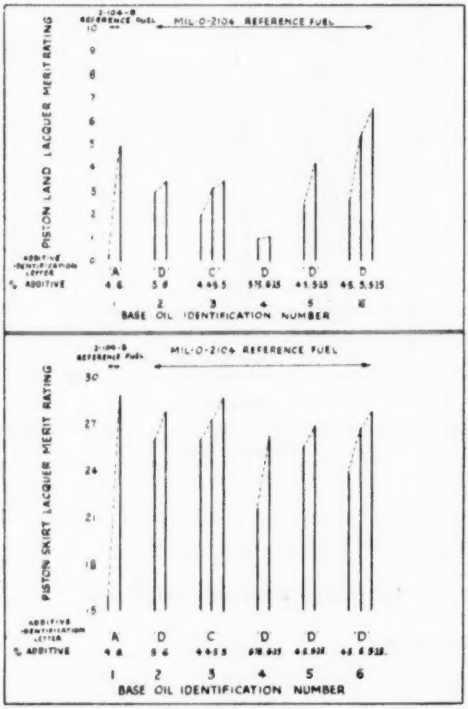


FIG 13

PETTER AV1 PISTON SKIRT AND LAND LACQUER RATINGS SHOWING ADDITIVE RESPONSE

(c) *Reproducibility of Test Results*

Before analysing in detail the uses of this procedure for production batch testing of additives and for correlation with AXS-1551 test procedure and field tests, it is first necessary to establish limits of reproducibility for the important items of the merit rating system.

The two most important items are considered to be piston skirt lacquer and piston land lacquer. Ring sticking is another important item, and for an oil to be of 2-104B, MIL-0-2104 or DEF/2101, or Supplement I standard there should be no ring sticking when tested with the appropriate grade of fuel.

Fig 15 shows some piston skirt lacquer merit rating results on various grades of identical oils which have been tested at least twice, and often on

different engines and rigs. Excluding oils H and O, piston skirt lacquer ratings come within a spread of 1·5.

In the case of oils H and O the spread of results is greater, but ring sticking occurred. Oil H is a regular grade oil and suffers moderately heavy ring sticking, and oil O is a 2-104B grade oil tested under Supplement I conditions and suffers light-moderate ring sticking. It is considered that this ring sticking is the most likely cause of the lower reproducibility.

Fig 16 shows the reproducibility of the land lacquer merit ratings, and for all the oils tested the maximum spread is approximately 1·5 merit rating out of a maximum possible of 10. Whilst this spread is wider pro-

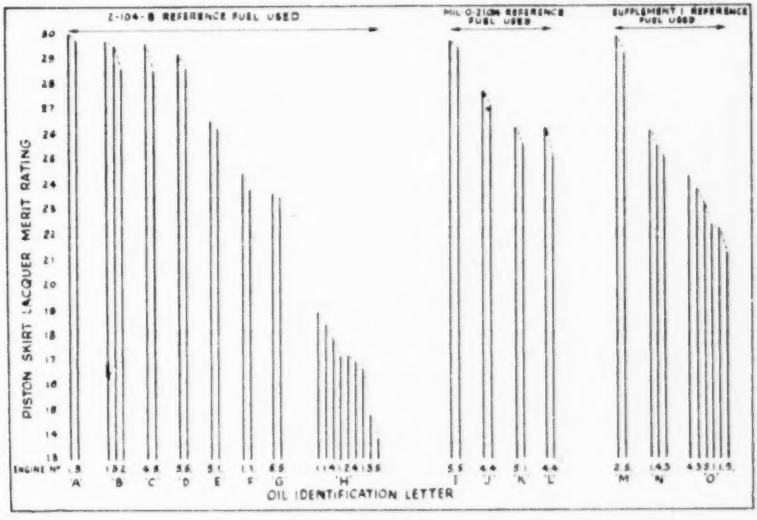


FIG 15

REPRODUCIBILITY OF PETTER AV1 PISTON SKIRT LACQUER MERIT RATINGS

portionately than is the case with skirt lacquer, the land lacquer rating has nevertheless proved to be useful in the segregation of oils for Mil-0-2104 or DEF/2101 qualification purposes.

Ring sticking is never easy to reproduce with any degree of consistency in engine tests. However, it has been found when testing the regular grade SAE 30 98 V.I. reference oil, previously referred to, on the low sulphur fuel, that the second and third compression rings are normally stuck to quite a severe degree with the top ring free, giving merit ratings ranging from 10 to 18 out of a maximum possible of 35; when tested on the Supplement I reference fuel the same oil would stick all three compression rings, forcing termination of the test due to lack of compression after anything between 80 and 120 hr.

Some less paraffinic base oils of medium V.I. have been less prone to ring sticking than the regular grade 98 V.I. reference oil, and have produced ring sticking merit ratings in the region of those given by some mildly detergent oils (*see* Fig 17). On the other hand, some mildly detergent oils

have shown light to moderate ring sticking of the third and possibly the second compression rings, resulting in merit ratings for this type of oil varying between 20 and 35. Some 2-104B grades of oil will produce ring sticking when tested with the Supplement I reference fuel, the merit ratings in such cases varying between 15 and 30, depending upon the precise quality of the oil.

In the few cases where MIL-0-2104 or DEF/2101 grades have been tested on the Supplement I reference fuel, these have not produced ring sticking.

Suspect results occur on all engines, even in the best regulated laboratories, and on very rare occasions the top compression ring has stuck without ring

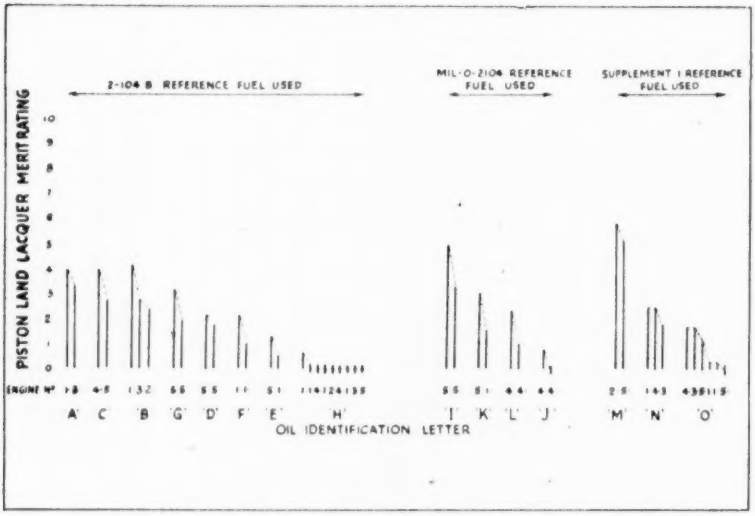

PISTON LAND LACQUER MERIT RATING
2-104 B REFERENCE FUEL USED
MIL-O-2104 REFERENCE FUEL USED
SUPPLEMENT I REFERENCE FUEL USED
ENGINE Nº
A C B G D F E H I K L J M N O
OIL IDENTIFICATION LETTER

FIG 16

REPRODUCIBILITY OF PETTER AV1 PISTON LAND LACQUER MERIT RATINGS

sticking of the second and third compression rings when testing 2-104B or Supplement I type oils on their respective reference fuels. In such rare cases (less than 1 per cent) repeat tests have shown no sticking of the top compression ring, and the sticking has been found to be either due to crown land cutting "nipping" the ring following faulty combustion, or to the presence of a small foreign body jammed between the ring and the groove, or to excessive carbon build up on the crown land due to faulty combustion. Ring sticking normally progresses from the third compression ring upwards, this being due to the fact that the lacquer build up on the sides of the rings and grooves forms on the third before the second and on the second before the first; in addition wear on the ring and groove side faces is greater in the case of the top ring, thus resulting in this ring remaining free for a longer period than the other two. It normally requires a high lacquer-forming fuel, such as the reference high sulphur fuel, to stick the top compression ring within the 120 hours test.

(d) *Batch Testing of Additives*

The two items of merit rating procedure used for comparison purposes are the piston skirt and land lacquer ratings, these being shown in Figs 18 and 19 for some recent production tests on a variety of additives.

Batch testing is carried out by first determining the amount of a reference additive required to give an acceptable AXS-1551 result when blended in the

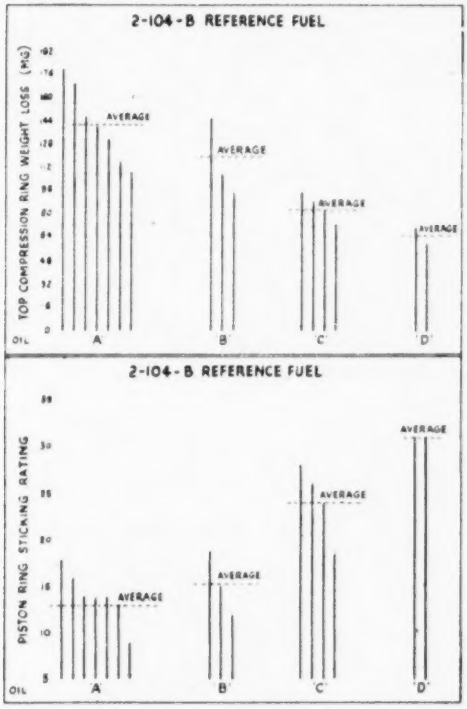


FIG 17

THE INFLUENCE OF DIFFERENT BASE OILS ON PISTON RING STICKING AND WEAR

98 V.I. SAE 30 reference oil. A sample from a production batch of additive is then blended in the same proportion in this base oil, and must give an acceptable result when tested on the AV1.

Dealing first with additives " A " and the newly introduced additive " B " designed to produce oils of 2-104B quality level, from the rather limited number of officially approved 2-104B oils which have been tested on the AV1 unit it is believed that the minimum permissible piston skirt lacquer rating is 23·0, and that the corresponding minimum piston land lacquer rating is 1·0.

Reference to Figs 18 and 19 shows that while the spread of results from batch to batch for additive " A " appears wide it is not unduly so, bearing in

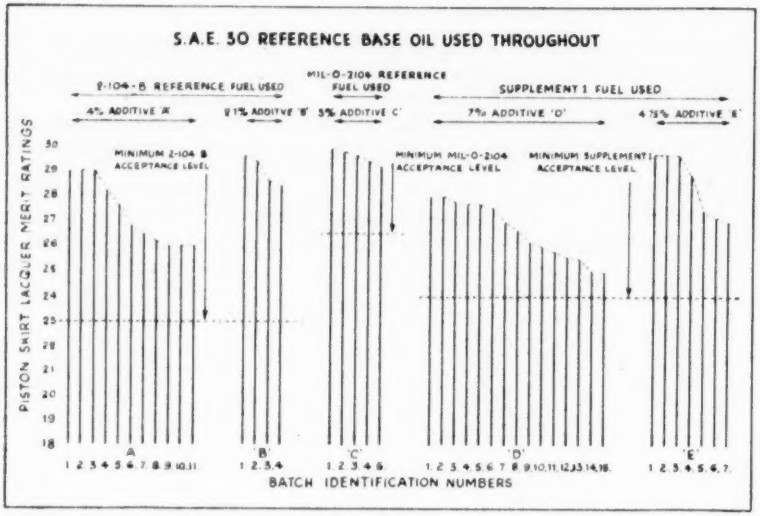

S.A.E. 30 REFERENCE BASE OIL USED THROUGHOUT
2-104-B REFERENCE FUEL USED
MIL-O-2104 REFERENCE FUEL USED
SUPPLEMENT 1 FUEL USED
4% ADDITIVE 'A'
2·1% ADDITIVE 'B'
3% ADDITIVE 'C'
7% ADDITIVE 'D'
4·75% ADDITIVE 'E'
MINIMUM 2-104 B ACCEPTANCE LEVEL
MINIMUM MIL-O-2104 ACCEPTANCE LEVEL
MINIMUM SUPPLEMENT 1 ACCEPTANCE LEVEL
PISTON SKIRT LACQUER MERIT RATINGS
BATCH IDENTIFICATION NUMBERS

FIG 18

PETTER AV1 PISTON SKIRT LACQUER MERIT RATINGS ON PRODUCTION BATCHES OF ADDITIVES

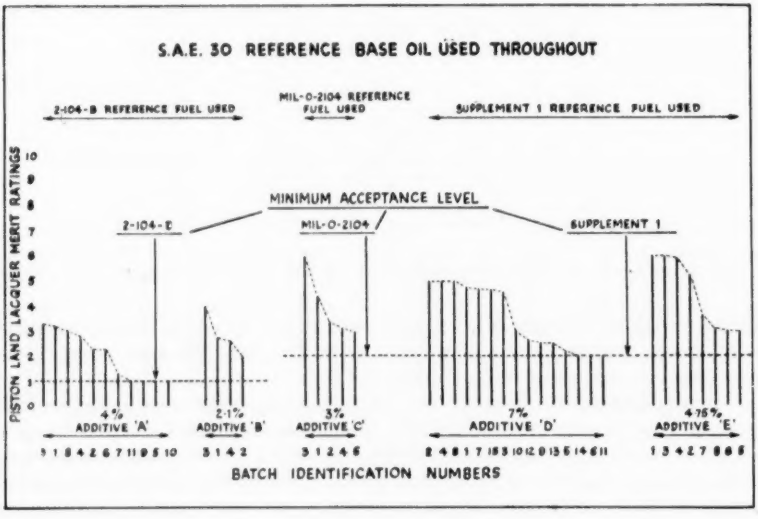


FIG 19

PETTER AV1 PISTON LAND LACQUER MERIT RATINGS ON PRODUCTION BATCHES OF ADDITIVES

mind that the spread is accounted for not only by normal batch variations in the additive, but also by differences in the results from test to test.

In the case of Supplement I oils, experience on the small quantity of officially approved oils which have been tested on the AV1 indicates that the minimum acceptable piston skirt lacquer rating is 24·0, and the minimum land lacquer rating is 2·0. Additives " D " and " E " are used for producing oils of Supplement I quality level.

As will be seen in the section dealing with Caterpillar correlation, the minimum acceptance limits for MIL-0-2104 or DEF/2101 qualification purposes are more clearly defined on account of the larger number of officially tested oils which have been used for correlation purposes, and for the piston skirt lacquer the merit rating is 26·5 and for the piston land lacquer 2·0.

Unfortunately there are not many results at MIL-0-2104 or DEF/2101 level on production batches of additive, since the first type of additive used for this work was similar to additive " D " but used in a reduced proportion. For production batch tests this was therefore tested at the Supplement I level.

(e) *Interpretation of the Various Merit Rating Items*

The usefulness of the piston skirt and land lacquer ratings has already been covered to some extent, but Fig 20 provides a composite summary of the average ratings to be expected on the various types of oils tested on the three reference fuels.

It is noticeable that the relative order of merit of the various types of oil is maintained throughout the fuel range. The graph also indicates the likely spread of results and, whilst in some instances there is slight overlapping between the various types of oils, it should be borne in mind that the spreads shown include not only variations from test to test but also cover variations within a given classification of oils.

Fig 21 also provides a similar composite picture for the top groove carbon, scraper ring sludge, and ring sticking ratings. Again it is noticeable that the relative order of merit of the different types of oil is maintained throughout the range of fuels.

Although the top groove carbon rating classifies the oils in the same relative order of merit throughout the fuel range, this rating is not too reliable, as there is a large spread in results. The reason for this is thought to be the sensitivity of the rate of build up of carbon to the small variations in combustion which occur from test to test. Nevertheless, it is noticeable that the regular grade oil always has an almost zero reading on the 2-104B, MIL-0-2104, and Supplement I reference fuels, and that the 2-104B type oils are also close to the zero mark on the high sulphur fuel, although rated higher on the low sulphur fuel. Summarizing, it would appear that if an oil is prone to producing excessive carbon at a particular fuel quality level, then this will always produce excessive carbon, but that an oil which does not possess carbon forming characteristics will on the average show a higher rating. If special importance is attached to the carbon rating, then at present it is advisable to carry out more than one test if the first result is not satisfactory.

Scraper ring sludge only occurs in the normal course of events with

regular grade oils, and the extent of this sludging will vary according to the type of oil being tested.

While scraper ring sludge provides information with regard to oils having a marked sludge forming tendency, some idea as to the relative sludge forming tendencies of 2-104B, MIL-0-2104 or DEF/2101, and Supplement I type oils, when tested with their appropriate reference fuels, can be obtained from the piston skirt sludge merit ratings. However, since the amount of sludge

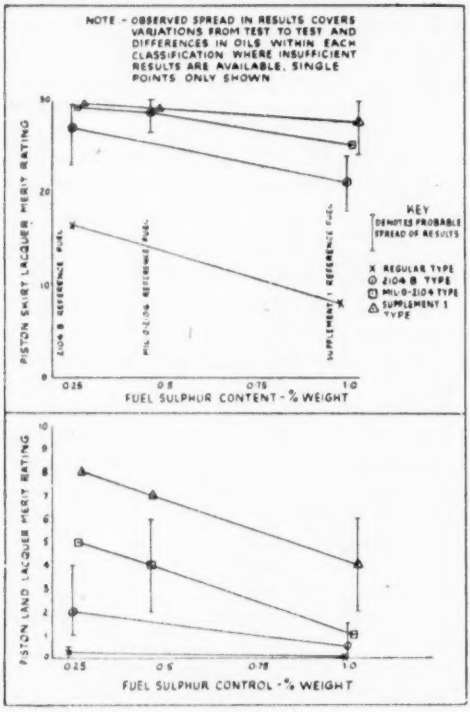

NOTE - OBSERVED SPREAD IN RESULTS COVERS VARIATIONS FROM TEST TO TEST AND DIFFERENCES IN OILS WITHIN EACH CLASSIFICATION WHERE INSUFFICIENT RESULTS ARE AVAILABLE. SINGLE POINTS ONLY SHOWN
PISTON SKIRT LACQUER MERIT RATING
KEY
DENOTES PROBABLE SPREAD OF RESULTS
X REGULAR TYPE
2104 B TYPE
MIL-0-2104 TYPE
SUPPLEMENT 1 TYPE
2104 B REFERENCE FUEL
MIL-0-2104 REFERENCE FUEL
SUPPLEMENT I REFERENCE FUEL
0.25
0.5
0.75
1.0
FUEL SULPHUR CONTENT - % WEIGHT
PISTON LAND LACQUER MERIT RATING
FUEL SULPHUR CONTROL - % WEIGHT

FIG 20

PETTER AV1 AVERAGE PISTON SKIRT AND LAND LACQUER MERIT RATINGS ON VARIOUS TYPES OF OILS AND FUELS

left on a piston after a light wipe to remove the oil is to some extent dependent on the operator, and in addition is somewhat more sensitive to slight variations in combustion characteristics than lacquer formation, it is necessary for true comparison purposes to assess the results of several tests.

Fig 22 shows some typical piston skirt sludge ratings obtained when testing batches of additives.

Some results are also shown for additive " A " when tested on the Supplement I reference fuel. It will be noted that less sludge is formed with this fuel than with the 2-104B reference fuel, and this lines up with the scraper ring sludge deposits when testing regular grade oils with both fuels.

Table XI summarizes average merit ratings for the various types of oils when tested with the different grades of fuels, and shows that the general components and crown cutting ratings fall in the same order of merit as the classification of the various grades of oils.

Photographs of Petter AV1 pistons are shown in Fig 23, and these represent average results for the various types of oils when tested with the

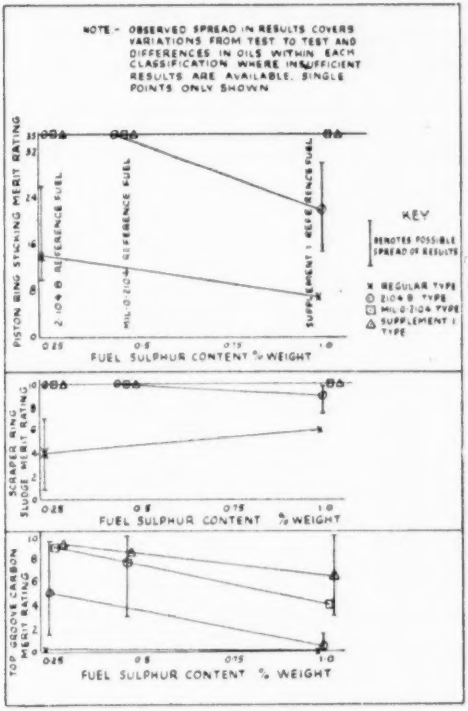

NOTE - OBSERVED SPREAD IN RESULTS COVERS VARIATIONS FROM TEST TO TEST AND DIFFERENCES IN OILS WITHIN EACH CLASSIFICATION WHERE INSUFFICIENT RESULTS ARE AVAILABLE. SINGLE POINTS ONLY SHOWN
PISTON RING STICKING MERIT RATING
2-104 B REFERENCE FUEL
MIL-O-2104 REFERENCE FUEL
SUPPLEMENT 1 REFERENCE FUEL
KEY
DENOTES POSSIBLE SPREAD OF RESULTS
X REGULAR TYPE
2-104 B TYPE
MIL-O-2104 TYPE
SUPPLEMENT 1 TYPE
FUEL SULPHUR CONTENT % WEIGHT
SCRAPER RING SLUDGE MERIT RATING
FUEL SULPHUR CONTENT % WEIGHT
TOP GROOVE CARBON MERIT RATING
FUEL SULPHUR CONTENT % WEIGHT

FIG 21

PETTER AV1 AVERAGE MERIT RATINGS ON VARIOUS TYPES OF OILS AND FUELS

different grades of fuel. These photographs should be studied in conjunction with Table XI.

CATERPILLAR CORRELATION

Evidence of some degree of correlation with the AXS-1551 test procedure has already been given, in so far as the various quality grades of oil tested on the AV1 unit have been placed in the same order of merit as indicated by the Caterpillar unit, and this is further borne out by the results shown in Fig 27. For the AV1 results to be of maximum value, however, correlation must go further, and it must be possible to state with a fair degree of certainty whether or not the oil tested on the AV1 would be acceptable

under the appropriate quality specification when tested according to the AXS-1551 procedure. Much work has been carried out in our laboratories with a view to showing that the AXS-1551 results can in fact be predicted from the AV1 test, and while the work is by no means complete, there are grounds for suggesting that the AV1 results do in certain respects predict the behaviour of the oil on the AXS-1551 procedure, and correctly classify oils as "pass," "borderline," or "failure," particularly in the MIL-0-2104 and DEF/2101 quality range, in which most of our experience has been concentrated. This statement must be qualified by the fact that most of the authors' experience has been on oils which are questionable on the AXS-

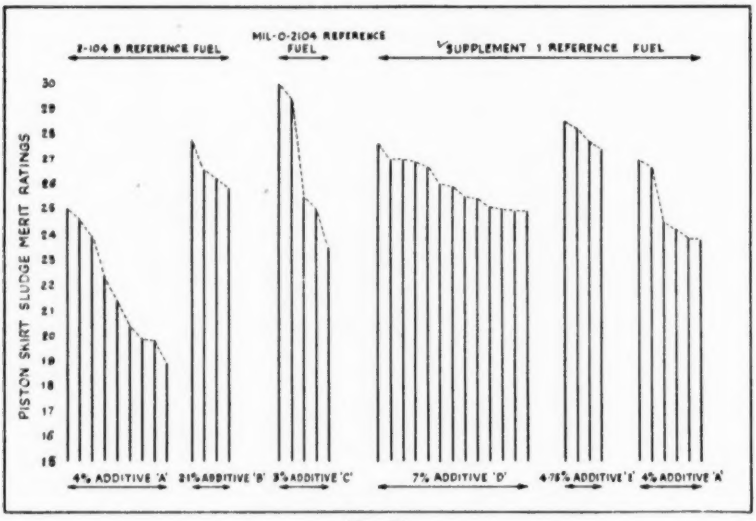


FIG 22

PETTER AV1 PISTON SKIRT SLUDGE MERIT RATINGS ON PRODUCTION BATCHES OF ADDITIVES

1551 procedure by virtue of lacquer formation rather than top ring groove filling. The importance of this will be seen from the definition of the acceptable standard for MIL-0-2104 qualification, viz.:

"Up to 25 per cent carbon filling of the clearance volume between the back of the piston ring and the inside of the ring groove is permitted in the top piston ring groove with not more than a trace of lacquer on or below the first land. Interpretation of this requirement will be based on the mature judgement by members of the Ordnance Engine Oil Reviewing Committee. Obviously overall piston cleanliness will be considered, for example ring groove plugging slightly in excess of 25 per cent may be acceptable in view of freedom from lacquer, and vice versa."

As far as AXS-1551 procedure goes, lacquer formation and top ring groove carbon deposits are therefore of equal importance. In carrying out the tests, however, top ring groove deposits appear to be over-ridingly influenced by the Caterpillar exhaust system design, and although tests on individual engines give reasonably good repeatability, this does not extend to tests carried out on other engines unless the exhaust systems are identical. Five

TABLE XI

Average Merit Ratings for Various Oil Types with Different Reference Fuels

Reference fuel	2-104B				MIL-0-2104				Supplement I			
Oil type	Regular	2-104B	MIL-0-2104 or DEF/2101	Supplement I	Regular	2-104B	MIL-0-2104 or DEF/2101	Supplement I	Regular *	2-104B	MIL-0-2104 or DEF/2101	Supplement I
Crown cutting rating (max 5)	3·7	3·9	4·2	4·3	—	—	4·1	4·3	3·4	3·7	4·0	4·2
Piston ring sticking rating (max 35)	14·0	35·0	35·0	35·0	—	—	35·0	35·0	7·0	22·0	35·0	35·0
General components deposit rating (max 10)	7·2	8·5	8·9	9·0	—	—	8·8	8·9	6·5	8·1	8·4	8·8
Scraper ring sludge deposit rating (max 10)	4·0	10·0	10·0	10·0	—	—	10·0	10·0	6·0	9·0	10·0	10·0
Piston land lacquer deposit rating (max 10)	0·1	2·0	5·0	8·0	—	—	4·0	7·0	0·0	0·5	1·0	4·0
Piston skirt lacquer deposit rating (max 30)	16·5	27·0	29·0	29·5	—	—	28·5	29·0	8·0	21·0	25·0	27·5
Total merit rating (max 100)	45·5	86·4	92·1	95·8	—	—	90·4	94·2	30·9	64·3	83·4	89·5
Total deposit rating (max 60)	27·8	47·5	52·9	56·5	—	—	51·3	54·9	20·5	38·6	44·4	50·3

* May not complete 120-hour test on account of ring sticking.

feet difference in the length of the exhaust pipe between cylinder head and first expansion chamber may result in doubling the top ring groove deposits. In general, however, except in very isolated cases, the top ring groove deposits at our laboratories have been below acceptable limits and have not caused undue concern. In any case the authors have no conclusive evidence that top ring groove carbon deposits on the Caterpillar do necessarily line up with any trouble experienced in service.

Referring now to borderline cases, it will readily be realized that it will never really be possible to say from tests on any other engine whether the AXS-1551 results on these oils will be accepted or rejected by the approving panel. This is partially on account of the somewhat indefinite nature of

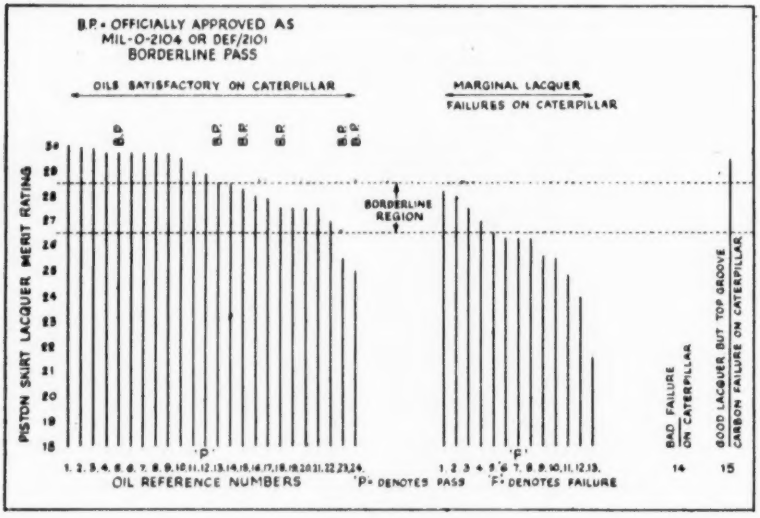

B.P. = OFFICIALLY APPROVED AS MIL-O-2104 OR DEF/2101 BORDERLINE PASS
OILS SATISFACTORY ON CATERPILLAR
MARGINAL LACQUER FAILURES ON CATERPILLAR
PISTON SKIRT LACQUER MERIT RATING
BORDERLINE REGION
OIL REFERENCE NUMBERS
'P' DENOTES PASS
'F' DENOTES FAILURE
BAD FAILURE ON CATERPILLAR
GOOD LACQUER BUT TOP GROOVE CARBON FAILURE ON CATERPILLAR

FIG 24

PETTER AV1 PISTON SKIRT LACQUER MERIT RATINGS ON MIL-0-2104 OR DEF/2101 TYPE OILS

the acceptance standard (particularly when the oil concerned is being judged both by the British and American committees) and also on account of inevitable variations which occur from test to test not only on the AV1 unit but also on the Caterpillar.

The questions of lacquer formation and top ring groove carbon deposits are now separately considered.

(a) *Lacquer Formation*

Figs 24 and 25 show the AV1 piston skirt and land lacquer ratings of oils which have passed and failed the MIL-0-2104 and DEF/2101 requirements of the AXS-1551 test procedure. From these results it appears that in general there is a region of 26·5 to 28·5 skirt lacquer rating in which the oils may be classified as " borderline "—that is, it is impossible to state whether

or not these oils would be acceptable. Above the upper limit all oils are acceptable, while below the lower limit oils would now be considered as failures, although in fact some time ago two oils (Nos P.23 and P.24), which incidentally both gave acceptable AV1 land lacquer deposits, were accepted as borderline pass oils by the Reviewing Board. Turning now to the land lacquer rating, if the region 2·0 to 4·0 is considered as borderline all oils above the upper limit are officially acceptable with one exception (No. F.6) which fails the AV1 test by virtue of its low skirt lacquer rating, while with one exception (No. P.15) * all oils below the lower limit have failed to gain

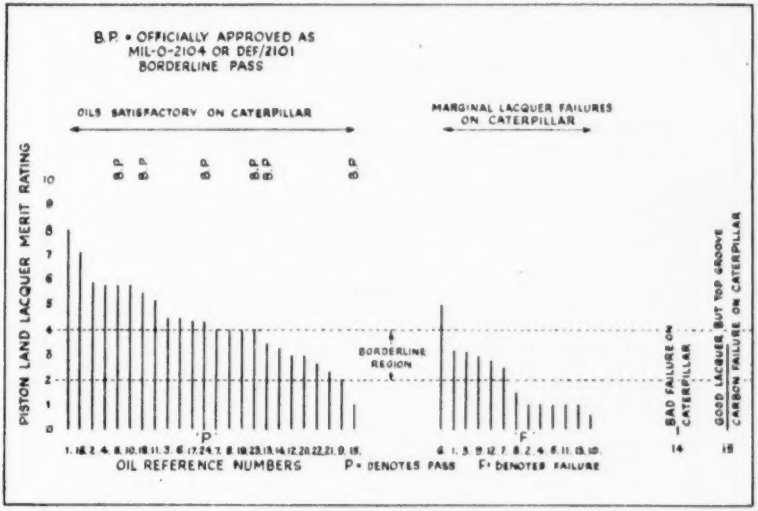

B.P. = OFFICIALLY APPROVED AS MIL-O-2104 OR DEF/2101 BORDERLINE PASS
OILS SATISFACTORY ON CATERPILLAR
MARGINAL LACQUER FAILURES ON CATERPILLAR
PISTON LAND LACQUER MERIT RATING
BORDERLINE REGION
BAD FAILURE ON CATERPILLAR
GOOD LACQUER BUT TOP GROOVE CARBON FAILURE ON CATERPILLAR
OIL REFERENCE NUMBERS
P = DENOTES PASS
F = DENOTES FAILURE

FIG 25

PETTER AV1 PISTON LAND LACQUER MERIT RATINGS ON MIL-O-2104 OR DEF/2101 TYPE OILS

official acceptance, and in fact this one exception gave a relatively high piston skirt lacquer rating. Between these limits it is impossible to state whether or not the oil would be acceptable.

Accepting the upper limits of both skirt and land lacquer ratings as being the figures to aim for, it is seen that if they are achieved there is every chance of successful acceptance. In the case of oils in which price consideration is the over-riding factor, official acceptance tests may be attempted on oils falling within either borderline category, and the official test results may or may not be acceptable, depending upon a variety of factors. For oils failing to meet the lower limit of either piston skirt or land lacquer, at least 90 per cent would be expected to fail if submitted to the AXS-1551 test procedure, and only in very exceptional circumstances would such attempts be made.

* Granted borderline pass acceptance.

(b) *Top Ring Groove Deposits*

AV1 top ring groove deposits for oils tested on the MIL-0-2104 or DEF/2101 test procedure are shown in Fig 26. Top ring groove deposit correlation from test to test is not yet sufficiently good to justify any conclusions as to the degree to which the deposits line up on the Caterpillar and AV1 units. It is noteworthy, however, that oils F.14 and F.15, which were rejected on the AXS-1551 procedure as giving top ring groove deposits outside the acceptable limit, gave high deposits also on the AV1, their ratings being only 0·5 and 2·0. Almost all other oils which were acceptable on the AXS-1551

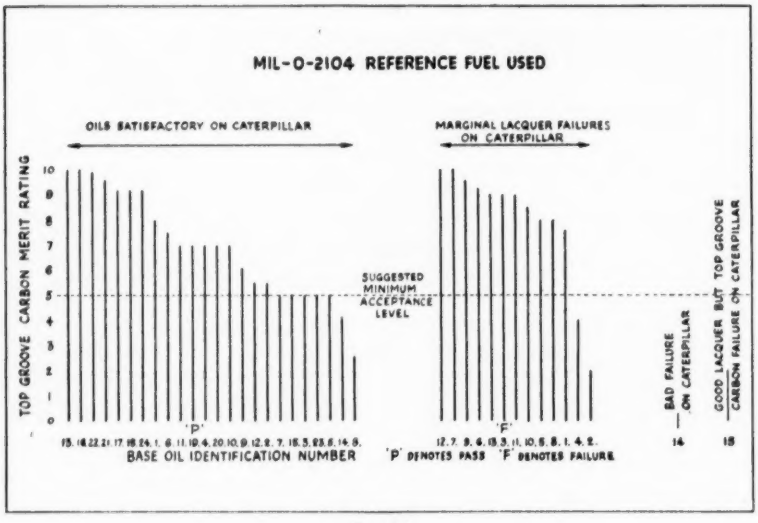

MIL-O-2104 REFERENCE FUEL USED
OILS SATISFACTORY ON CATERPILLAR
MARGINAL LACQUER FAILURES ON CATERPILLAR
TOP GROOVE CARBON MERIT RATING
SUGGESTED MINIMUM ACCEPTANCE LEVEL
BAD FAILURE ON CATERPILLAR
GOOD LACQUER BUT TOP GROOVE CARBON FAILURE ON CATERPILLAR
BASE OIL IDENTIFICATION NUMBER
'P' DENOTES PASS 'F' DENOTES FAILURE

FIG 26

PETTER AV1 TOP PISTON RING GROOVE CARBON MERIT RATINGS ON MIL-0-2104 OR DEF/2101 TYPE OILS

procedure as regards top ring groove deposits gave ratings on the AV1 above 5, and consequently it is the authors' practice to insist on this figure as a minimum before submitting an oil to official test. Experience generally indicates that a good top ring groove rating on the AV1 indicates a good rating on the AXS-1551 test, but a rating towards 5 on the AV1 does not necessarily mean that the AXS-1551 result will be towards borderline. The reason for this probably lies in some uncontrolled combustion effect on the AV1 not yet localized.

When opportunity permits, further AV1 work is to be carried out on oils known to produce high AXS-1551 top ring groove deposits with the object of investigating whether there is any degree of correlation between AV1 land lacquer rating and AXS-1551 top ring groove deposits, since the mean temperature of these would appear to be approximately the same. Similar work will be carried out in an endeavour to obtain correlation between top ring groove deposits.

Wear Characteristics

It is not possible on 120-hour AT/4 test procedure to obtain sufficient cylinder liner wear for comparison purposes between oils and, therefore, wear on the top compression ring as measured by its weight loss is used.

Weight loss figures for the various grades of oils when tested on the reference fuels are given in Figs 28, 29, and 30, and these results are averaged and summarized in Fig 31, which also shows, where possible, the approximate spread likely to occur. These results show that the various types of oils are classified in order of merit throughout the fuel range, although there is some overlapping in the spread of results, due both to variations from test to test and differences between the individual oils tested. It is probable

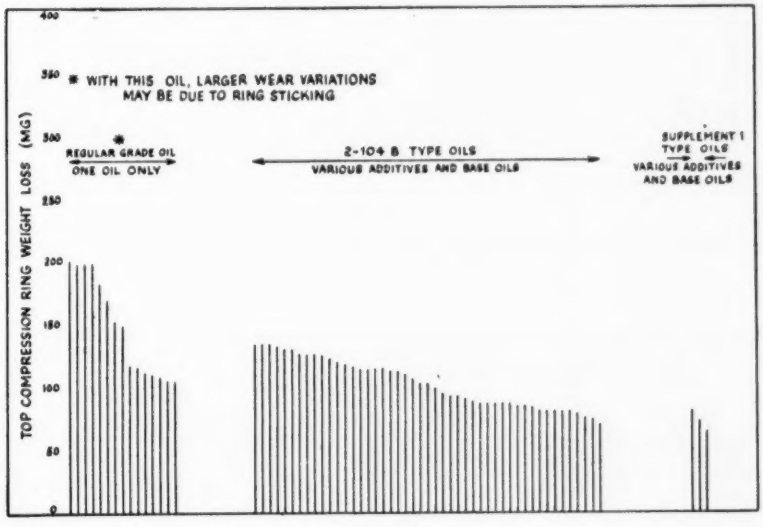


Fig 28

PETTER AV1 TOP COMPRESSION RING WEAR ON 0·25% SULPHUR FUEL WITH VARIOUS GRADES OF OILS

from the spread for a given type of oil that if, for example, two Supplement I type oils gave weight losses of 50 and 100 mg, then it would not be possible to state that the oil giving only 50 mg weight loss had superior anti-wear characteristics, since this difference in the results is considered to come within the limits of reproducibility.

The wear figures given for regular grade oil refer only to the SAE 30 98 V.I. reference oil, since many of the other wear figures quoted refer to production batch tests on additives using this base oil, but other lower V.I. regular grades can sometimes produce lower wear figures, as has already been shown in Fig 17. It is difficult to say whether these lower wear figures are due to the smaller degree of ring sticking that goes with such oils, or are a result of the softer deposits often associated with them.

No attempt has been made to correlate the individual wear figures on

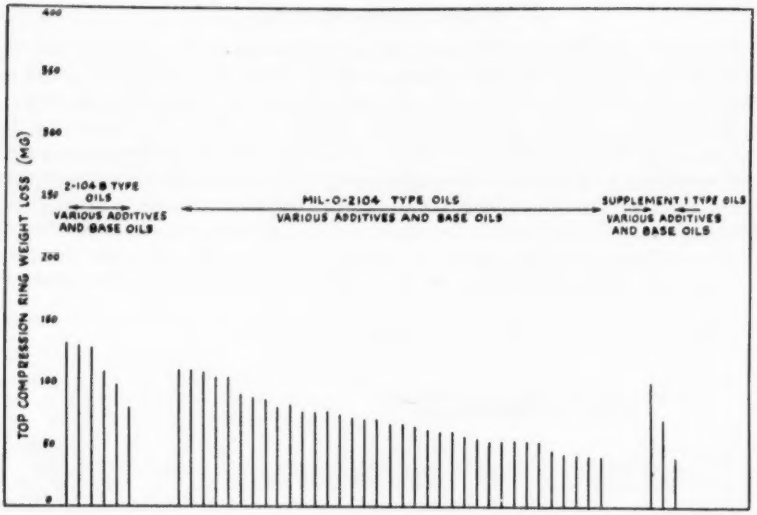

TOP COMPRESSION RING WEIGHT LOSS (MG)
2-104 B TYPE OILS
VARIOUS ADDITIVES AND BASE OILS
MIL-O-2104 TYPE OILS
VARIOUS ADDITIVES AND BASE OILS
SUPPLEMENT 1 TYPE OILS
VARIOUS ADDITIVES AND BASE OILS

FIG 29

PETTER AV1 TOP COMPRESSION RING WEAR ON 0·45% SULPHUR FUEL WITH VARIOUS GRADES OF OILS

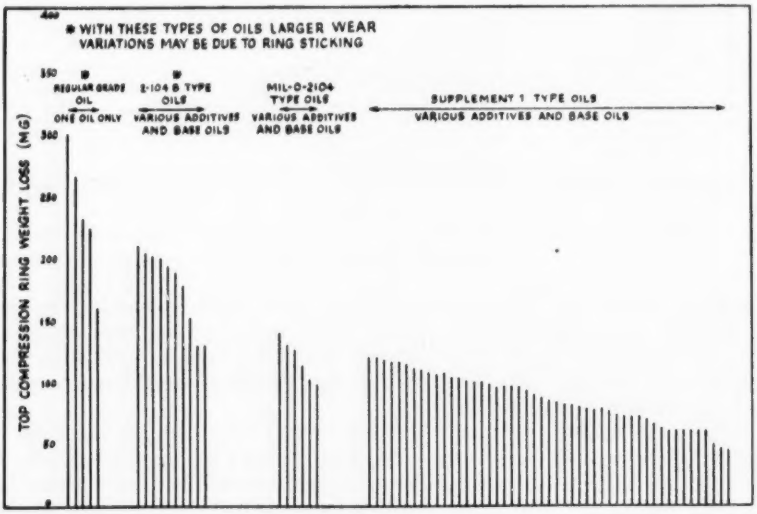

* WITH THESE TYPES OF OILS LARGER WEAR VARIATIONS MAY BE DUE TO RING STICKING
* REGULAR GRADE OIL
ONE OIL ONLY
* 2-104 B TYPE OILS
VARIOUS ADDITIVES AND BASE OILS
MIL-O-2104 TYPE OILS
VARIOUS ADDITIVES AND BASE OILS
SUPPLEMENT 1 TYPE OILS
VARIOUS ADDITIVES AND BASE OILS
TOP COMPRESSION RING WEIGHT LOSS (MG)

FIG 30

PETTER AV1 TOP COMPRESSION RING WEAR ON 1·0% SULPHUR FUEL WITH VARIOUS GRADES OF OILS

MIL-0-2104 or DEF/2101 type oils, which have been tested on both the Caterpillar and AV1 units, since none of the satisfactory or borderline failure oils referred to in the previous section on Caterpillar correlation came outside the maximum acceptable MIL-0-2104 or DEF/2101 wear limits.

Influence of Fuels on Test Results

It is evident that the AV1 unit is sensitive to different fuel quality levels, and these effects are perhaps best summarized in Figs 20, 21, and 31.

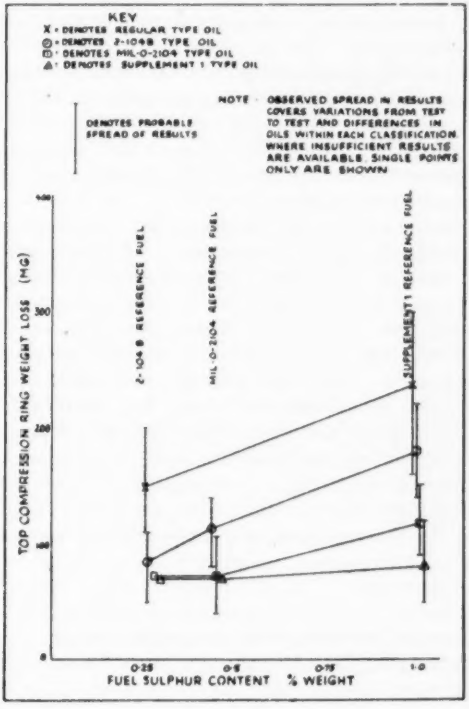

KEY
X = DENOTES REGULAR TYPE OIL
◎ = DENOTES J-1045 TYPE OIL
□ = DENOTES MIL-O-2104 TYPE OIL
△ = DENOTES SUPPLEMENT 1 TYPE OIL
DENOTES PROBABLE SPREAD OF RESULTS
NOTE - OBSERVED SPREAD IN RESULTS COVERS VARIATIONS FROM TEST TO TEST AND DIFFERENCES IN OILS WITHIN EACH CLASSIFICATION WHERE INSUFFICIENT RESULTS ARE AVAILABLE SINGLE POINTS ONLY ARE SHOWN
J-104 B REFERENCE FUEL
MIL O-2104 REFERENCE FUEL
SUPPLEMENT 1 REFERENCE FUEL
TOP COMPRESSION RING WEIGHT LOSS (MG)
0·25
0·5
0·75
1·0
FUEL SULPHUR CONTENT % WEIGHT

Fig 31

AVERAGE PETTER AV1 TOP RING WEAR FOR VARIOUS TYPES OF OILS AND FUELS

Referring first to the effect of fuels on engine deposits, as shown in Figs 20 and 21, it can be seen that the deposits increase with sulphur content, although these increases are less noticeable with oils of superior grade. This is the logical sequence of events that is known to occur in practice with fuels of differing sulphur content.

An increase in the sulphur content of a fuel is also known to increase the rate of wear, and Fig 31 shows that the AV1 unit also produces results that agree with this. Once again it is noticeable that these increases are less apparent with the superior grade oils.

Correlation with Service Performance

The authors are well aware that certain service tests have given no clear cut differentiation between straight oils and oils believed to be of 2-104B standard, whereas L.1 Caterpillar tests did show considerable difference. The view that this is general experience cannot be accepted, and whilst agreeing that no one engine test can hope to cover all service conditions, it is believed that by making the test conditions sufficiently exacting it is possible to separate those oils which will by and large give satisfactory service performance from those which will not. The piston lacquer requirements of the AXS-1551 procedure do in general ensure this, and numerous instances could be quoted in support. On the other hand, there is no reason to suppose that results on this procedure should necessarily correlate with service experience under continuous low temperature, continuous starting and stopping or other extreme conditions well away from the test conditions, although it has been found that MIL-0-2104 or DEF/2101 and Supplement I type oils have proved effective in practice in reducing both wear and deposits for both petrol and diesel engines.

In a similar manner the AV1 test procedure quoted in this paper does, in general, line up with service experience, and has given results well in agreement with service experience on the same oils over a wide variety of engines, as will be seen from the following examples selected from many. In considering correlation, or lack of correlation, between laboratory test and service results, it should be remembered that in service seldom is it possible to maintain a close control on the fuel used, whereas laboratory tests are, or should be, carried out under the ideal conditions of using reference fuels. Similarly, under service conditions there are, in many cases, variations in maintenance procedure from test to test, which do not occur in the laboratory. Again, owing to the close control over filter maintenance and cleanliness of assembly, wear in the laboratory is mostly confined to the corrosive type. In service, however, dusty atmospheres and less control over these other features means that wear is a combination of corrosive plus abrasive components, and consequently the expected improvement in wear due to the use of improved oils cannot always be fully borne out in service. Generally, however, it can be said that wherever an oil has shown itself capable of reducing wear on the AV1 test a similar feature has been shown in service.

A few examples of correlation between laboratory and field service on different types of engines will now be considered.

(1) *Bus Operation—Local Service*

Fig 32 shows typical pistons removed from a fleet of 9·6-litre AEC engines fitted to double decker buses on inter-town service after 100,000 miles. Piston " A " ran throughout on a straight oil, whilst Piston " B " ran on a Supplement I oil. In the case of Piston " A " scraper ring slots were completely plugged up every 25,000 miles, and the compression rings were on the point of sticking; re-ringing was therefore carried out at these mileages. No such servicing was necessary in the case of the Supplement I oil, where the compression rings remained free and the scraper rings clean

throughout. Corresponding AV1 pistons run on the same oils are also shown in Fig 32.

Samples of fuel taken during the tests gave average sulphur contents of 0·7 per cent. It is evident, therefore, that the AV1 test is comparable to approximately 30,000 miles running with an AEC 9·6-litre double decker vehicle under inter-town service conditions.

Service cylinder bore wear measurements showed a ratio of 2·7 : 1 in favour of the Supplement I oil, as compared with a piston ring weight loss ratio of approximately 2·5 : 1 in the case of the AV1 laboratory tests.

(2) *Power House Operation*

Fig 33 compares representative pistons taken from two Davey-Paxman engines after concurrent running in a power house for 450 hours, " A " running on a 2-104B type oil, and " B " on the same base oil treated to Supplement I standard. Average sulphur content of the fuel was 1·0 per cent. Running was terminated on the 2-104B oil after 450 hours due to power loss and excessive blow-by through sticking of the second and third compression rings and the top scraper ring. The other engine at this period was showing no fall-off in power, although the second compression ring was partially stuck. Corresponding AV1 tests on the two oils are also shown in Fig 33.

Fig 34 compares pistons run on an 8-cyl power house engine, " A " on the same straight oil as used for Test (1) after 214 hours operation, and " B " after 1270 hours operation on the same Supplement I oil as used for Test (1). Both tests were at high load, and samples of fuel taken indicated an average sulphur content of 0·7 per cent. For comparative AV1 pistons, reference should be made to Fig 34. As a matter of interest subsequent tests on a lower V.I. Supplement I oil showing much better AV1 results when tested on 1·0 per cent sulphur fuel gave even more satisfactory piston conditions after 3089 hours power house running on the 8-cyl engine.

(3) *Tractor Operation*

One case where particularly wide divergence between laboratory test results and service experience might be anticipated is that of single-cylinder two-stroke diesel tractor engines. That this is not necessarily so is shown in Fig 35, which illustrates pistons from a tractor of this type : " A," after 205 hours on a straight untreated oil ; " B," after 2000 hours on a MIL-0-2104 oil ; " C " after 1750 hours on a Supplement I oil.

Fuel samples were not regularly taken, but samples which were obtained indicated an average sulphur content of 0·7 per cent. Corresponding AV1 pistons on the same three oils, and using a fuel of 0·7 per cent, are shown in Fig 35.

It will be seen from the four cases quoted above, which include four different types and makes of engine and three very different types of operation, that there is reasonably good correlation between the AV1 and service tests, both as regards lacquer deposits on the piston and the extent of ring sticking. However, none of the cases quoted involved frequent stopping and starting, which the AV1 AT/4 procedure does not attempt to simulate.

Piston Temperature Test

It has been suggested that correlation between various engines can only be expected if their piston temperatures correspond; thus, correlation between the AV1 and the Caterpillar, it is said, can only be anticipated if their top ring groove temperatures are similar. As a corollary it was suggested that service correlation could only be expected under running conditions which bring the piston temperature up to that of the AV1. It is

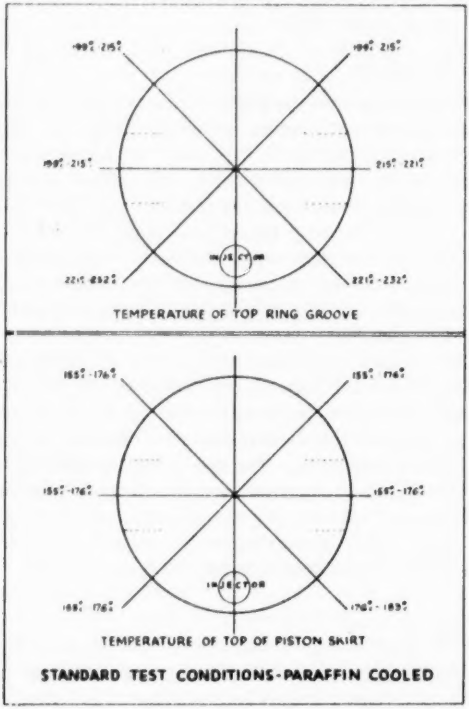


Fig 36

TEMPERATURE OF AV1 TOP RING GROOVE AND SKIRT, AS MEASURED BY "SENTINELS"

possible that for a direct comparison of top ring groove deposit with top ring groove deposit, there may be some truth in this suggestion, although it has already been shown that the general appearance of pistons after AV1 test on a number of oils corresponds very well with the appearance of pistons taken from service after running under a wide variety of conditions, probably few of which would give piston temperatures as high as on the AV1.

One of the objects of the AT/4 procedure on the AV1 has been to produce, in 120 hours, deterioration of the piston condition comparable with that which takes many hundreds of hours service running, and another has been

to give some relative idea of how the oil may be expected to perform on the AXS-1551 test in 480 hours running. To do this in the relatively short running time the severity of one or more running conditions must be increased.

The piston temperature on the AV1 is, therefore, higher than that on the Caterpillar and tests have been carried out to find out by how much it is higher. In addition, temperature tests have been made to determine the

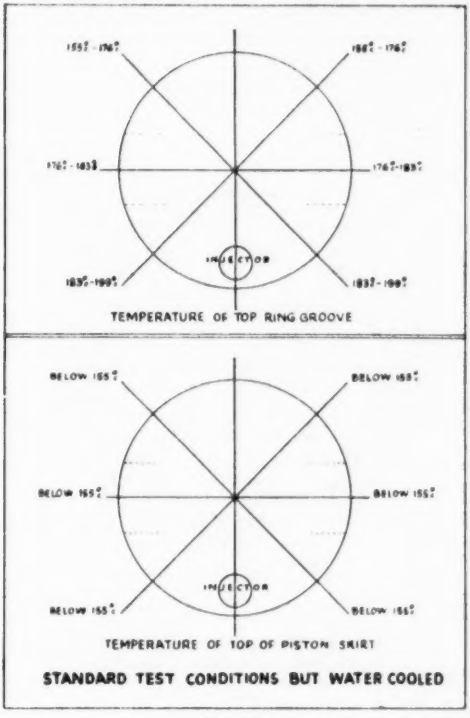


FIG 37

TEMPERATURE OF AV1 TOP RING GROOVE AND SKIRT AS MEASURED BY "SENTINELS"

influence of various test conditions on the top ring groove temperature of the AV1.

Fig 36 shows the distribution of temperature as determined by sentinels round (*a*) the top ring groove and (*b*) the piston skirt between the fourth ring groove and the top of the gudgeon pin hole. As might be expected, the highest piston temperature is reached in the region nearest the injector, and there is a temperature gradient of about 20° C to the lowest temperature position immediately opposite the injector. Skirt temperatures are roughly 50° C below ring groove temperatures. Shown in Fig 37 are ring groove and skirt temperatures obtained with the engine running under the same standard conditions but cooled with water instead of kerosine.

Temperatures throughout are approximately 40° C lower. Fig 38 illustrates piston temperatures measured by sentinels on the Caterpillar unit under L.1 conditions. It will be noted that these temperatures are approximately the same as those on the water-cooled AV1 engine.

By fitting to the piston a copper–constantan thermocouple with sliding contacts it has been possible to determine the influence of variation of test conditions on top ring groove temperature during running. The thermocouple was in fact fitted at an angle of 45° to the injector so that the temper-

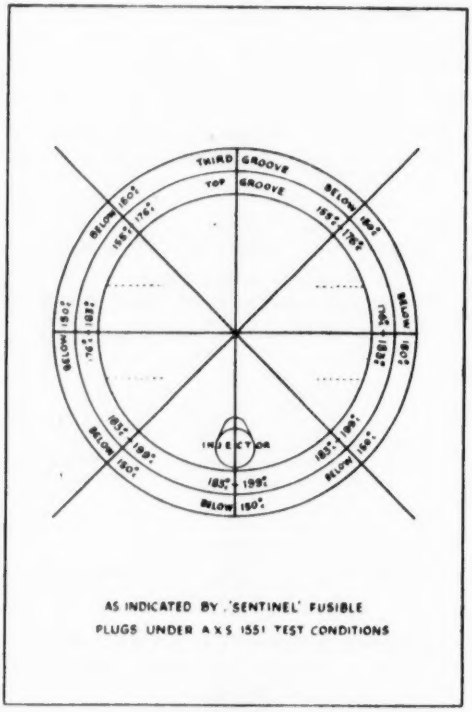


FIG 38

CATERPILLAR PISTON RING GROOVE TEMPERATURES

atures measured do not quite correspond to the maximum. Fig 39 shows that, keeping the same coolant outlet temperatures, the variation in piston temperature is only $7\frac{1}{2}$° C for a variation in coolant flow of 80 gal/min. Fig 41 shows that coolant outlet temperature is not too critical if the flow is maintained constant, 40° C difference in this only influencing the piston temperature 13° C. Oil temperature in the sump as shown by Fig 42 has no influence over a wide range from 40° to 90° C. On the other hand, b.m.e.p. (Fig 40) does appreciably influence the piston temperature, 10 b.m.e.p. making a difference of 12° C. It will be noted also that there is a good agreement between the results of temperature measurement by means of thermocouples and measurement by means of sentinels.

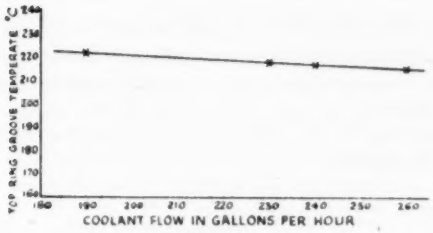


FIG 39

INFLUENCE OF COOLANT FLOW ON TOP RING GROOVE TEMPERATURE —ALL OTHER CONDITIONS STANDARD EXCEPT THE COOLANT INLET TEMPERATURE

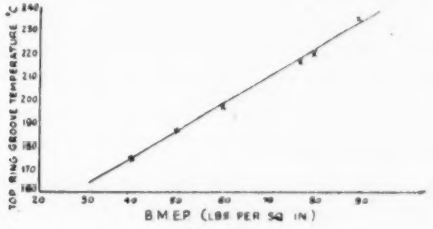


FIG 40

INFLUENCE OF B.M.E.P. ON TOP RING GROOVE TEMPERATURE ALL OTHER CONDITIONS STANDARD

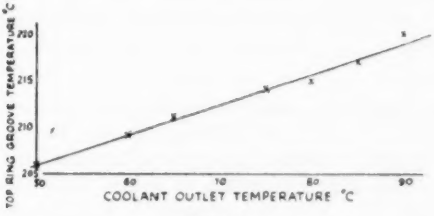


FIG 41

INFLUENCE OF COOLANT OUTLET TEMPERATURE ON TOP RING GROOVE TEMPERATURE— ALL OTHER CONDITIONS STANDARD EXCEPT THE COOLANT INLET TEMPERATURE

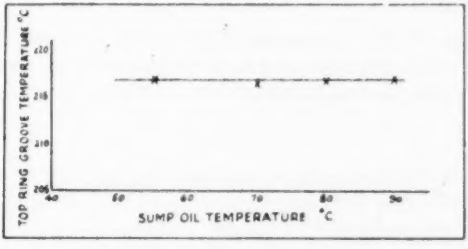


FIG 42

INFLUENCE OF SUMP OIL TEMPERATURE ON TOP RING GROOVE TEMPERATURE— ALL OTHER CONDITIONS STANDARD

Influence of Variations in Test Conditions on Results

Engine tests carried out on treated and on untreated oils with one test condition varied from standard, the remaining conditions as far as possible being standard, agreed generally with what would be anticipated from the known influence of these conditions on top ring groove temperature. Each of these is now considered.

(a) *Coolant Flow*

All other conditions, including the coolant outlet temperature, were held constant and the coolant flow varied to cover a range of inlet temperatures. Using a solvent-refined 98 V.I. straight oil, between 140 and 320 gal/hr, the total merit rating varied between 30·4 and 49·7, most of this difference being attributed to divergence in ring sticking. Hence the tolerance of ± 10 specified on the standardized rate of flow of 240 gal/hr will probably correspond roughly to a spread of 2 to 2·5 points on average straight oil, or negligible spread on heavy duty oils.

(b) *Coolant Outlet Temperature*

Keeping coolant flow constant but varying coolant outlet temperature between 70° and 90° C indicated that, with 2-104B type oils, there was no great difference between 70° and 85° C but that there was a fall-off of 13 points distributed between ring sticking and piston lacquer rating on increasing the outlet temperature from 85° to 90° C. With Supplement I type oils the variation was not significant, but with straight oils variation occurred over the whole range, depending upon the base oil used.

(c) *B.M.E.P.*

With all other conditions standard, variation in b.m.e.p. from 67 to 87 showed a reduction of 9 points in total merit rating using a 2-104B type oil, made up of a progressive reduction in piston lacquer rating throughout the range combined with the occurrence of some slight ring sticking in the b.m.e.p. range 77 to 87. With Supplement I oils the variation was reduced to about one-third, with straight oils it was increased, the extent of increase depending upon the base oil.

(d) *Oil Temperature*

Within a range of oil temperature of 55° to 80° C the results obtained on all H.D. type treated oils appeared to be independent of sump oil temperature. 55° C was adopted as standard for convenience.

(e) *Oil Pressure*

Maintaining the same bearing clearances throughout it was shown that variation in oil pressure between 6 and 13 p.s.i. had no significant influence on test results whatever the oil tested. Variation in oil pressure due to crank and bearing wear would be anticipated, therefore, to be unimportant. Big-end bearing seizures occurred when the oil pressure was reduced to 4·5 p.s.i.

(f) *Piston to Liner Clearance*

Extra piston to liner clearance up to 0·003-inch was found to have no significant influence on test results, but increases over 0·003 inch caused a fall-off in piston lacquer rating.

(g) *Oil Consumption*

With SAE 30 oil variation in oil consumption from 0·01 to 0·10 pints/hr appeared to have no significant influence on test results.

(h) *Fuel and Coolant Dilution of the Oil*

It is difficult to separate by physical tests the individual extent of kerosine and diesel fuel dilution, but the total of these at the completion of a test usually lies well below 1·5 per cent. Tests to determine the individual influence of both diluents by separately bleeding each into the crankcase oil and maintaining the total dilution at a predetermined level throughout the test, indicated that with both treated and untreated oils the dilution effect was not too significant, even up to a total of about 6 per cent; above this there was a progressive reduction in lacquer merit ratings. A maximum of 3·0 per cent dilution would therefore be considered satisfactory.

(i) *Fuel Spill Valve Timing*

Normal spill valve timing is set at 21 to 22 BTDC; a further 2° advance on this promotes ring sticking in borderline cases. Retarding the timing results in poor fuel consumption and possibly more top groove carbon filling.

(j) *Fuel Injection Pressure*

Variation in fuel injection pressure between 2250 and 2652 p.s.i. appeared to have no influence on the test results. On the other hand, injectors required less servicing at the higher pressure.

(k) *Valve Timing*

The influence of valve timing and overlap has not been investigated.

Fuels Used

With the exception of that used for MIL-0-2104 correlation testing, the fuels used for the whole of the tests covered by this paper are reference fuels selected by the Engine Tests of Lubricants Panel of the Institute of Petroleum, and comply with the appropriate CRC specification. So far no fuel exactly complying with the MIL-0-2104 fuel specification has been generally available to laboratories in the U.K., and as a consequence the American Army Ordnance Oil Reviewing Board agreed to accept the use by our laboratories of a fuel having a higher cetane number than that laid down (49 as compared with 45), provided that the sulphur content of the fuel was maintained on the high side (0·45 per cent as compared with a specification minimum of 0·35 per cent). This fuel has been used throughout the AXS-1551 and AV1 correlation programme, and does in fact comply with the latest DEF/2101 specification. Table XII gives the properties of all three fuels used for the tests covered by this report.

TABLE XII

Data on Fuels Used for Caterpillar and AV1 Tests

	2-104B specification limits	Fuel used	DEF/2101 * and MIL-0-2104 specification limits	Fuel used	Supplement I † specification limits	Fuel used
Distillation, ° F:						
50% point	—	—	500 min	518	—	518
90% point	550–600	610	600–640	620	550–600	643
End point	675 max	676	650–690	671	675 max	670
Sulphur content, % w	0·4% max	0·25	0·35 min (natural) (sulphur)	0·45	1·0% min	1·03
Cetane number	43–53	51	40–45	49	was 43–53	43
Carbon residue on 10% residium, %	0·2 max	0·03	—	—	0·2 max	0·02
Ash, %	0·01 max	Less than 0·01	—	—	0·01 max	Less than 0·01
Kin visc, c/s at 100° F	1·6–4·5	3·03	1·6–4·5	3·09	1·6–4·5	3·8
Flash point, ° F	100 min or legal	164	100 min or legal	164	100 min or legal	172
Pour point, ° F	20 max	10	20 max	Fluid at 0° F	20 max	Fluid at 0° F
Water and sediment, % vol	0·05 max	Trace	0·05 max	Trace	0·05 max	Trace
Corrosion	Pass	Pass	Pass	Pass	Pass	Pass
Alkali and mineral acids	None	None	None	None	None	None

* From 1.8.52 DEF/2101 specified fuel sulphur content 0·40% minimum, cetane number 45 to 50.
† From March 1951 Supplement I specified same limits as MIL-0-2104 except sulphur content of 0·95 to 1·05%

TROUBLES ENCOUNTERED ON AV1 ENGINE

Most of the troubles encountered in running the AV1 engine for oil test purposes are connected with the injection system, and probably tie up with the necessity for the maintenance of scrupulous cleanliness both of the fuel and the whole of the injection system. It may be of interest, however, to consider some of the difficulties experienced.

Difficulty	Remedy
(1) *Unsatisfactory Fuel Consumption*	
(a) *Engine Tightness on Assembly.* On a few occasions, immediately after the complete rebuild of an engine with correct clearances, it has been found impossible to obtain satisfactory fuel consumption at the completion of the 8 hours running-in. Liner distortion due to the oil seal ring being too tight in its groove can cause this.	Complete a further 4 hours running-in, maintaining the fuel consumption within correct limits by reducing the load.
(b) *Unsatisfactory Spray from Injector*	
(i) Due to build up of deposits on nozzle.	Clean and re-set injector. Some special fuels have given injector fouling within 10 hours running. Normally injectors will complete a test without cleaning.
(ii) Sticking of injector plunger due to lacquer build up.	Most prevalent on high sulphur fuels, and may necessitate changes during a test.
(iii) Dirt in injector.	Inspect all filters. Make sure that injectors and fuel pipes are kept in dustproof containers and that the fuel pump outlet is sealed when the engine is stripped.

Difficulty	Remedy
(c) *Wear of pad on fuel pump operating rocker*	Re-grind pad profile. Chrome plate or stellite if possible.
(d) *Incorrect compression ratio*	Re-check piston to cylinder head clearance.
(e) *Leaking air-cell joint*	Check faces and renew joint washer.
(f) *Injection Timing incorrect*	Re-set.
(2) *Coolant Dilution*	
(a) *Bottom Seal Ring.* Under extremes of tolerance the standard AV1 neoprene lower sealing ring is prone to give leakage and it is essential to use the " Cub " ring, Part No. T.100. Cutting of the ring by the cylinder block or twisting must be avoided.	Check condition and type of seal ring, wet ring on assembling liner into the block or lightly smear with lanoline.
(b) *Top Joint.* Some gas leakage takes place from the cylinder to the coolant circulating space as will be seen from Fig 43 which shows a typical copper asbestos cylinder head gasket after running. During the first few hours after engine assembly a slight gas blow often takes place through the washer to atmosphere. Comparative tests with and without these leakages indicate that they do not influence the test results. Gas leakage appears to be due to the lack of " bridge " strength in the head, and consequently cannot entirely be eliminated by refacing the cylinder head and block, although occasional very light refacing helps. The distortion, however, only extremely rarely appears to be responsible for any coolant leakage into the oil. Laminated aluminium gaskets are not the solution to the gas leakage problem.	Gas leakage can be reduced to a minimum by tightening the cylinder head studs down to a torque of 120 ft/lb and re-tightening to this same torque after run-in.
(3) *Pocketing of Valves*	
After a considerable number of tests (possibly 30) pocketing of the valves may occur; when this is such that the face of a new valve is 0·060 inch below the face of the head, rectify.	Rectify by fitting exhaust and inlet valve inserts.
(4) *Valve Sticking*	
On some oil and fuel combinations.	Minimized by countersinking both ends of valve guides and fitting 50 per cent stronger valve springs than standard.
(5) *Loss of Oil Pressure*	
Other than when determining the minimum possible running oil pressure, the only bearing failures which have occurred during testing have been due to complete loss in oil pressure on two occasions through wear on the ball fitted to the non-return valve in the oil pump, thus allowing this ball to jam in the open position.	Oil pump balls are renewed on complete engine strip every eight tests.
(6) *Oil Consumption*	
When in the first instance three parallel ground compression rings were used, oil consumptions above 0·200 pints/hr were sometimes experienced on SAE 30 oils. Adoption of taper turning for the two lower compression rings has reduced the maximum oil consumption on this grade of oil to below 0·100 pints/hr and gives an average consumption of below 0·040 pints/hr.	

Conclusion

Although not without faults, and certainly not as trouble free as the Caterpillar unit, the Petters AVI Laboratory Oil Test Engine when run under the test procedure detailed in this paper does provide a convenient and relatively simple method of comparing both straight and additive treated oils, and the results so obtained bear a close resemblance to experience under average service conditions.

The use of kerosine as a coolant enables a test duration of only 120 hours to be used without the disadvantages associated with ethylene glycol, and without the disadvantage of crankcase oil temperatures far outside practical conditions. The low initial and running costs of what is basically a production unit enable a batch of engines to be operated at a cost lower than that necessary for the installation and operation of one Caterpillar unit. Correlation between the AV1 AT/4 and the Caterpillar AXS-1551 procedures when testing 2-104B, MIL-0-2104, or Supplement I oils is, except in borderline cases, sufficiently close as regards piston lacquer deposits (which the authors believe to be the most important requirement for prevention of service troubles) to enable the AV1 unit to be used with reasonable confidence as a means of determining the most economical additive treatment. This method of selecting oils allows considerable saving both in testing time and expenditure, since the alternative of assessing oils by running feeler tests on the Caterpillar unit of 120 or 240 hours duration is by no means a reliable prediction of the performance of the oil on the 480-hour test. The relatively low running cost of the unit also allows it to be used for testing production batches of H.D. additives.

Finally, the AV1 unit, while showing a similar degree of sensitivity to fuel as the Caterpillar, is not unduly sensitive to small changes in operating conditions.

Acknowledgments

The authors express their thanks to the directors of Anglamol Ltd. for permission to publish this paper, and to Petters Ltd. and Hepworth & Grandage Ltd. for help given with engines and components respectively.

APPENDIX I

Comparative Cost of AV1 Test

The cost of carrying out testing on the AV1 unit will vary considerably from laboratory to laboratory, and will depend upon the number of units running at one time in the laboratory concerned as well as upon the general system of accounting adopted. The following relative costs, however, are in reasonable ratio to one another.

Test engine	Test procedure	Duration, hr	Relative cost per test		Relative capital cost of engine, test bed, and instrumentation
			Excluding chemical laboratory work associated with test and preparation of reports	Inclusive of chemical laboratory work and preparation of illustrated report	
Cat.	AXS-1551 or CRC-L.1-545	480	450	360	700
AV1	AT/4	120	100	100	100

APPENDIX II

Coolant Characteristics

Typical Distillation Range of Kerosine Used as a Coolant

	°C
I.B.P.	151
10%	182
20%	192
30%	202
40%	210
50%	219
60%	228
70%	237
80%	248
90%	262
95%	273
F.B.P.	283
Recovery	98%
Residue	2%

THE EVALUATION OF H.D. OILS BY MEANS OF SMALL PETROL ENGINES

By G. H. J. Simmons *

Summary

This paper briefly describes the Lauson engine and test procedures used in the evaluation of lubricating oils. It also refers to those factors which have been found, during the course of several years experience of the unit, to affect test results.

The degree of correlation obtained with both Caterpillar and Chevrolet is discussed, together with modifications designed to improve it, and it is concluded that whilst an engine of the Lauson type should not be considered a substitute for these engines in specifications requiring their use, very valuable information on oil and additive combinations can be obtained.

Introduction

For many years the Chevrolet and Caterpillar engine test procedures, among others, have been used for the evaluation of H.D. oils, and their incorporation in specifications such as MIL-0-2104 is well known. Both tests are expensive and, the Caterpillar in particular, time consuming, and many laboratories in the U.S. sought for some simple engine and test procedure which would provide preliminary screening in respect of oxidation, bearing corrosion, and detergency.

Several laboratories adopted the Lauson model LF, a simple side valve,

* Messrs. C. C. Wakefield & Co. Ltd.

four-stroke, water-cooled petrol engine with fly-wheel magneto ignition. Test procedures were in most cases peculiar to the laboratory concerned, and many individual engine modifications were made.

Even before 1944 the COS Bench Test Group of the CLR Engine Oils Division had carried out co-operative tests through one of its panels, and at the SAE meeting in January 1944 the Group moved that the panel on Lauson design should be instructed to proceed with the development of a standardized engine. By November of the same year a tentative design had been approved, and by June 1946 the first prototype engines had been completed and were sent to Armour and certain other research laboratories for preliminary tests. A year later, when quite a number of engines had been in operation, the Analysis and Research Technique Panels, from a review of these exploratory tests, were able to recommend three provisional research techniques for presentation to the Bench Test Group. Since this date a considerable amount of co-operative research has been carried out in the U.S. and numerous modifications made to the engine and procedures, but this paper is restricted to the practical experience of the engine by a laboratory in the U.K.

Details of Engine

The present unit, the Model H-2 Oil Test Engine, is a single-cylinder L-head type of $2\frac{5}{8}$ inches bore $\times$ $2\frac{3}{4}$ inches stroke, with a compression ratio of 5 : 1. Replaceable dry liners are fitted, and the pistons are aluminium alloy of very simple form with two compression rings and one scraper ring above the gudgeon pin. Both main bearings are ball races, and the big end is fitted with replaceable steel backed copper–lead bearings of exactly the same composition as used in the Chevrolet L.4 test.

Cooling is operated on the thermo-syphon evaporative principle, condensation of the coolant vapour being effected by water flowing through a closely wound copper coil in the cooling tower above the cylinder head.

The oil sump has a very thick base, machined externally for uniform heat transfer, to which three 500-watt strip heaters are clamped. Lubrication is by simple splash, the oil being supplied by a gear pump to a tray into which the connecting rod dips. The lower bearing cap is fitted with a dipper for this purpose.

Engine speed is governed by a ball-type governor, but can be varied within wide limits by external manual control. A standard two arm paddle fan with guard absorbs the power developed.

Ease of dismantling has been studied in that an inspection cover is provided on the side of the crankcase for inspection of connecting rod varnish, and through which the bearing shells can be removed for weighing. Furthermore, the complete cylinder block, together with its cooling system and the loading fan, is hinged to the top of the sump, and the removal of six studs allows the engine to be swung over for removal of piston and bearings.

Other features include a controlled variable crankcase breather and standardized locations in the jacket coolant system and sump for the insertion of thermocouples.

Experimental

The three research techniques which had been suggested were :—

(*a*) high jacket temperature—to study detergency characteristics;

(*b*) low jacket temperature with high oil temperature—to study oxidation stability and bearing corrosion characteristics;

(*c*) combination research technique—to make a quick study of all properties evaluated by (*a*) and (*b*).

The major test conditions common to the three procedures were as follows :—

Speed, r.p.m.	1840 ± 20
Load, b.h.p.	1·86
Ignition advance	25° BTDC
Piston clearance, inch	0·006–0·007
Bearing clearance, inch	0·001–0·003
Air fuel ratio	12·5 ± 0·5 : 1
Initial oil fill	2 lb
Oil make-up	Add to original level every 10 hr.
Crankcase breather valve	¼ turn open
Fuel	As specified for the Chevrolet L.4 test.

The specifically different conditions for the three procedures were :—

(*a*) High Jacket Temperature :	
Jacket temp, ° F	350° ± 5
Oil sump temp, ° F	180° ± 5
Test duration, hr	100
(*b*) Low Jacket Temperature–High Oil Sump Temperature :	
Jacket temp, ° F	210° ± 2
Oil sump temp, ° F	280° ± 5
Test duration, hr	60
(*c*) Combination Research Technique :	
Jacket temp, ° F	350° ± 5
Oil sump temp, ° F	225° ± 5
Test duration, hr	100

For procedure (*b*) distilled water is used as the coolant, and for procedures (*a*) and (*c*) ethylene glycol, the water content of which is previously adjusted to give a boiling point of 350° F.

Bearing shells are weighed before and after test to determine weight loss, and the piston is assessed on the same rating scale as that used for the Chevrolet L.4 test, *i.e.*, 0 to 10, where 0 is the condition when deposits have reached a maximum, the piston being completely covered with black varnish, and 10 representing a condition with no deposits. Other parts of the engine have not, up to the moment, been numerically rated, as their condition is usually comparable with that of the piston, but a written description is made of the amount of sludge, etc.

Both intermediate and final samples of the used oil are taken for laboratory examination, the usual tests being viscosity, pentane insoluble, and neutralization value. No strict relationship has been noted between the used oil tests and either bearing corrosion or piston rating, with the exception that the use of additives designed to improve these characteristics usually reduces viscosity increase and pentane insoluble to a considerable extent.

The type of oil also affects the values obtained, and some naphthenic oils, even when the additive combination contains enough anti-oxidant to comply with bearing corrosion requirements, will give rise to large viscosity increases. In these respects, Lauson used-oil results are very similar to those found for the Chevrolet test.

The first batch of new engines arrived in the U.K. in 1947. Since September 1947 hundreds of tests have been completed, the majority of the work having been carried out by the low jacket high sump temperature procedure and by the combination procedure. Comparatively few tests have been conducted according to method (*a*). The results obtained showed no particular advantage over those obtained from the combination procedure, and less information was obtained on bearing corrosion. Other types of test, mainly utilizing much lower temperatures, have been carried out using these engines, but are outside the scope of this paper.

Before going into the question of the degree of correlation obtained with the larger engines, and of the attempts made to improve it, it may be useful to consider various operational factors and their effects, particularly on precision and on the actual test results.

Oil Consumption

Excessive oil consumption usually results in dirty pistons, often with a blackish lacquer as opposed to the normal ambers and browns, and has been found to invalidate a considerable number of tests. Bearing corrosion, on the other hand, is either unaffected or reduced, and used oil tests are usually better with a high oil consumption, as would be expected owing to the large amount of make-up necessary.

In some of the earlier tests the high oil consumption experienced was due partly to leakage, particularly when experiments were made with high degrees of crankcase ventilation. The cause and the remedy was usually fairly obvious, and various engine modifications have largely eliminated this condition.

By far the biggest factor in oil control appeared to be the piston rings. The first twenty or thirty tests, unfortunately, had to be run with incorrect piston rings, the only rings available being those originally supplied for the old model LF engine. The scraper rings for this assembly were of the conventional slotted type, and during this period oil consumption was extremely variable and often reached very high proportions, the rate experienced varying between 5 and 37 g/hr. The oil control rings in the correct assembly were of quite a different type, the contact area being reduced practically to two knife edges on either side of the slots obviously giving a much higher unit radial pressure. Their use effected a great improvement in the consistency of the oil consumption, and the very high rates were no longer experienced.

Occasionally, however, high oil consumption (up to 15 g/hr) still occurred, and variations even of this order were considered to be unduly great. It was felt that the scraper rings had to carry practically the whole burden of oil control until the gas rings became properly run in, and with normal rings this process was often not satisfactorily completed in the comparatively short test periods. About two years ago, taper-faced gas rings of similar

design to those used in the Chevrolet were tried out, and have proved very successful in keeping the general level of oil consumption below 5 g/hr.

The foregoing remarks refer mainly to the low jacket temperature procedure; in the combination procedure oil consumption has always been higher, but some improvement has been achieved.

Crankcase Ventilation

When steps were taken to meter the volume of air passed through the crankcase it was found that the proposed test condition, *i.e.*, to keep the crankcase breather valve ¼ turn open, gave insufficiently accurate control. Frequent gas meter readings are now taken to ensure constant ventilation.

It was hoped that a relationship could be established between crankcase ventilation and oil oxidation, but variations of air flow in the range from 10 to 40 cu. ft/hr did not appear to be a very significant factor in this respect. Less than 10 cu. ft., however, tended to reduce oxidation, and no ventilation at all produced a very clean piston with practically no bearing corrosion. The maximum air flow which could be obtained was 40 cu. ft/hr and even before this figure was reached excessive oil consumption became a problem. The condition finally adopted was a ventilation rate of 20 cu. ft/hr; an intermediate figure which could easily be maintained, and which also corresponded fairly closely to the condition provided by the ¼ open position on some of the engines.

Weight of Initial Oil Charge

Because, in the early stages, thermometers of rather bulky dimensions had to be used to record sump oil temperature, instead of the specially designed thermocouples, just under 3 lb oil was required in order to keep the thermometer bulbs completely covered.

As soon as it became practicable to reduce the oil fill to 2 lb it was found that the general oil oxidation rate with its accompanying bearing corrosion and varnish formation increased somewhat, and reproducibility of results was improved.

Sump Oil Temperature

It is essential for repeatability that strict control be exercised over this factor, and the 10° F range allowed in the tentative procedures appears to be too wide. After temperature recorders were installed to enable control to be maintained within $\pm 2°$ F, much better repeatability was obtained.

Type of Fuel

For correlation with the Caterpillar engine a change was made to non-leaded petrol. This reduced somewhat the severity of the test and also the heavy scraper ring blocking previously experienced. It was considered, however, that this was unimportant compared with the advantage gained by eliminating the lead which is not a constituent of diesel fuels.

General

Type of exhaust system, cylinder distortion, excessive blow-by, excessively rich mixture, and leakage of the glycol coolant have all been found to give rise to anomalous results.

Repeatability, Reproducibility, and Correlation

If all the factors previously listed as affecting precision can be controlled satisfactorily, both repeatability (duplicate tests on the same engine) and reproducibility (tests on same oil in different engines) are fairly good. Owing to the number of engines available and the comparatively short test period, it is usually the practice to carry out duplicate tests on different engines on each oil. If these compare fairly closely, the result is considered valid, but if there is considerable disagreement further tests are undertaken.

With regard to the question of correlation with either the Caterpillar or Chevrolet test, it must be understood that the fact that an oil passes the arbitrary limits which have been postulated for the appropriate Lauson test is no guarantee that it will pass satisfactorily on the larger engines, although it may well do so in a number of cases. It can be said, however, that if the oil fails the Lauson test it is not worth while proceeding any further with it. In cases, therefore, where a number of oil and additive combinations have to be quickly assessed, or where a number of routine control tests have to be made, the Lauson engine can prove a very useful tool in the preliminary stages.

Correlation with the Caterpillar L.1 Test

Using the combination research procedure it has been found that the Lauson engine will differentiate, without difficulty, on piston rating between straight mineral oils, premium oils, and oils to 2-104B, MIL-0-2104, and Supplement I specifications. The differentiation between the two latter, however, is not marked. Table I shows the order of piston rating, ring sticking, and bearing weight loss which may be expected :—

Table I

	Piston rating (CRC)	Ring sticking	Bearing wt loss, mg
Straight mineral	1·0– 2·5	Stuck	80 upwards
Premium	3·0– 6·0	Variable	Under 20
2-104B	7·0– 9·0	Free	Under 20
MIL-0-2104	9·0–10·0	Free	Under 20
Supplement I	9·5–10·0	Free	Under 20

It will be seen that on piston rating Supplement I is the limit of the Lauson evaluation, the piston skirts often being completely clean, with only a trace of lacquer on the lands and in the grooves. Supplement II, therefore, cannot be evaluated by this procedure. The condition of the ring belt area further assists in differentiating between the three H.D. classes, 2-104B often giving rise to quite heavy brown or black lacquer, although the piston skirt is practically clean.

These results are, of course, obtained using petrol (lead-free and of very low sulphur content) as the fuel. It is known that some laboratories, using other engines, have obtained good correlation with Caterpillar results by adding sulphur, usually in the form of carbon disulphide, to the fuel. This method would have been applied to the Lausons had not Petter engines, which could use exactly the same fuel as the Caterpillar, become available,

giving the prospect of even better correlation. Even using the existing test procedure, however, the Lauson can still play a part in the preliminary assessment, and on one of the few occasions where a departure from normal practice was made, and the Caterpillar test was carried out first, the potential usefulness of the smaller engine was immediately apparent. On this occasion an experimental batch of Supplement I oil failed in the Caterpillar through excessive ring groove packing, and subsequent Lauson tests showed a piston rating of below 9. Had the Lauson test been carried out first, considerable time and expense would have been saved.

The Caterpillar test is not really designed for assessing straight mineral and premium oils, but their behaviour in the Lauson is included in Table I for interest.

Correlation with the Chevrolet L.4 Test

A considerable degree of correlation between the low jacket temperature procedure and the Chevrolet L.4 test has been found, and in most cases the Lauson rates oils in the same order as the Chevrolet. There are, however, certain differences in the two tests for which allowance must be made. To understand these it is necessary to realize that the Chevrolet does not assess detergency to any extent. It is essentially an oil oxidation and bearing corrosion test, and will not differentiate between the various categories of H.D. oils, *e.g.*, 2-104B, MIL-0-2104 and Supplements I and II. It will place a premium oil in the same class as the foregoing, and solvent-refined Pennsylvanian or Mid-Continent oils, even without additives, will usually give a piston rating of between 8 and 9 and adequate engine cleanliness, and will only fail on account of copper–lead bearing corrosion. In general, it is mainly oils of the Coastal type which produce varnished pistons and sludged engines in the L.4 test.

Using the low jacket temperature procedure, the Lauson shows greater differences in engine cleanliness than the Chevrolet, although it has its limitations. It will differentiate in this respect between straight oils, between straight oils of the high V.I. solvent-refined type and premium oils, and to some extent between premium and H.D. oils. No differentiation is, however, shown between the various classes of H.D. oil.

With regard to oil oxidation and bearing corrosion this procedure is unfortunately not as critical as the Chevrolet. In the early stages of our experience with these engines it appeared probable that an oil giving a bearing loss of under 20 mg in the Lauson would pass the Chevrolet, but it has since become necessary to modify this view because with quite small dosages of anti-oxidant additives a large variety of oils were found to comply with this limit, whereas the same concentration, particularly in some types of solvent refined Mid-Continent oils of high oxidation susceptibility, was insufficient to prevent undue bearing corrosion in the Chevrolet L.4 test.

Table II gives some examples in illustration of the foregoing statements. Oils A to I show the order of agreement generally found between the two tests, while X, Y, and Z illustrate the anomalies. It should be explained that oils X and Y only contain a small amount of anti-oxidant additive and oil Z was an experimental H.D. oil where the proportion of anti-oxidant was found to be inadequate.

Because of the shortage and general high cost of raw materials, quite apart from possible technical disadvantages, it is not desirable to use excessive concentrations of additives, but only sufficient to ensure the satisfactory performance of the finished product. It is therefore important to

TABLE II

Oil	Type	Chevrolet			Lauson		
		Piston rating CRC	Bearing loss, mg	Visc incr, %	Piston rating CRC	Bearing loss, mg	Visc incr, %
A	Sol. ref. Mid-Cont, high V.I., straight	9·4	3545	86·0	8·4	135	40·0
B	" " " " " "	9·3	1054	20·0	8·1	90	9·0
C	" " " " " "	8·7	800	52·0	6·0	200	45·0
D	" " blend, med V.I., straight	8·3	490	47·5	7·5	27	30·0
E	" " Mid-Cont, high V.I., premium type	9·1	177	27·0	7·8	14	23·0
F	" " Coastal, med V.I., premium type	9·2	226	11·0	7·2	3	6·0
G	" " " " " "	5·1	156	76·0	5·2	8	22·0
H	" " Mid-Cont, high V.I., H.D. type	9·6	62	7·0	9·3	8	9·5
I	" " Coastal, med V.I., H.D. type	9·1	130	20·0	8·5	4	4·0
X	" " Mid-Cont, high V.I., premium type	9·0	400	25·0	8·0	10	16·0
Y	" " " " " "	9·3	2590	56·5	8·6	6	5·0
Z	" " " " " H.D. type	9·1	752	25·0	9·0	13	12·5

be able to compare, in the engine test laboratory, the effect of quite small additional amounts of anti-oxidant additives.

A number of modifications to the low jacket temperature procedure have been tried in an attempt to obtain more exact correlation with the Chevrolet, particularly with the type of oil on which most disagreement has been experienced. The easiest and most obvious approach was to increase, stage by stage, the bulk oil temperature, and when this is raised to 320° F the test shows better agreement on bearing corrosion with solvent refined Mid-Continent oils. Unfortunately, under these conditions, piston lacquering is much more severe, and pronounced differences previously shown between some oils in this respect are no longer present. Moreover, a temperature increase of this order accelerates the test in a manner rendering it possibly unduly remote from practical conditions.

Increasing the speed to 2400 r.p.m., the maximum possible with the standard air brake which at this speed provides a load of 4 b.h.p., with retention of the original oil temperature of 280° F, also appeared promising, but it was found difficult to maintain these test conditions, as the engine is practically on its peak and therefore somewhat less reliable.

Work is now proceeding with the bearing area reduced to some 40 per cent of its original area which gives, at 1840 r.p.m., approximately the same bearing loading as for the complete bearing at 2400 r.p.m. and one which is also more comparable with the conditions found in the Chevrolet test. Results so far show figures for bearing corrosion closely similar to those obtained at the higher speed with no attendant disadvantages, apart from a somewhat higher oil viscosity increase. This modification has the effect of bringing the relative numerical values of bearing corrosion obtained in the Lauson much closer to the Chevrolet results.

During this work advantage has been taken of the simplicity of the engine design to remove and weigh the bearings at 10-hour intervals, thus en-

abling the development of oxidation to be followed and the induction period of the onset of bearing corrosion estimated graphically. It is felt that whatever conditions are adopted, some test of this type, run for an indefinite time with intermediate bearing inspections to determine the period of induction, is likely to be far more satisfactory, particularly from the research and correlation point of view, than any test of arbitrarily fixed duration.

These remarks apply with equal force to the Chevrolet L.4 test, the repeatability of which is not good in the case of borderline oils, which may give reasonable passes and bad failures alternately, if the induction period corresponds approximately with the standard test duration. It is worth recording at this point that although the Lauson, as has already been stated, is usually less severe than the Chevrolet, there have been occasions when a pass obtained on a single L.4 test has not been confirmed by the smaller engine, and further tests then carried out on the Chevrolet have shown the borderline nature of the oil and additive combination.

Unfortunately the Chevrolet is not nearly so accessible as the Lauson, and intermediate bearing inspections entail a considerable amount of work in dismantling and reassembly.

Conclusions

It may well be that it is impossible to obtain strict correlation between any one engine test and another, of a different type, with all possible combinations of oils and additives. If, however, an engine such as the Lauson is used with discernment, and a background of experience built up in conjunction with the results obtained in other types of engine, it is capable of giving the oil or additive manufacturer valuable assistance in improving his products, from the early stages of comparison of the quality and additive response of basic oils, up to the finished diesel lubricant.

On the other hand, if economic or other reasons restrict the test installation to one or two engines of the Lauson type, our experience shows that it is inadvisable to use procedures based on such engines as substitutes for specified Caterpillar or Chevrolet tests.

Acknowledgments

The author wishes to express his thanks to Messrs. C. C. Wakefield & Co. Ltd. for permission to use the material on which this paper is based, and also to a number of his colleagues for their valuable assistance.

THE TESTING OF I.C. ENGINE LUBRICATING OILS BY THE BLOGRO ENGINE UNDER SPARK AND COMPRESSION IGNITION CONDITIONS

By R. J. S. PERRY, B.Sc. (Associate Member)

INTRODUCTION

THE need for the development of an engine test for I.C. engine lubricants was appreciated by the Organization at its formation.

It was also appreciated that the test should satisfy the following requirements :—

It must be repeatable and must clearly differentiate the service quality of lubricants.

It must be economic in time and material so that it should be available to and within the resources of the majority of the petroleum trade.

A test of short duration was necessary. Available space and desirable capital expenditure limit the number of engines which may be usefully installed. It was, therefore, desirable that at least twenty tests should be made with each engine per annum in order that trade requirements should not encounter undue delay.

The engine must also be suitable for research.

Bearing in mind the wartime research in the field of engine testing, it was decided that a research engine should be developed which would take advantage of the data acquired. The test would be based on the same successful principle of testing the oil under arduous conditions, and would rate oils on the number of test hours completed, as distinct from running to an arbitrary number of hours and assessing the condition of the piston.

THE TEST BED

Crankcase

This is of the dry sump type, and is designed to be robust, easily dismantled, assembled, and cleaned. All inaccessible oilways are avoided, and the number of bearings through which the oil passes are reduced to a minimum in order that repeat tests on the same oil shall give an identical pattern of oil flow through the engine.

The crankcase does permit the use of various sizes of cylinder assembly by alteration of the adaptor plate, the use of two- or four-stroke cycle engines, etc.

The connecting rod is fitted with either a white metal or copper–lead big end bush.

The Cylinder Assembly

The sleeve valve cylinder assembly used in this test was adopted because it avoided hot spots, and cooling could be more easily repeated from test to

* The British Lubricating Oil & Grease Research Organization Ltd.

test and the cylinder assembly temperatures observed by the fitting of thermocouples.

The whole assembly is machined to close limits.

The initial cost of the assembly is comparatively high, but it has a very long life.

The assembly is designed around a Leyland standard piston, supplied to close limits by Messrs Wellworthy Ltd, and which will not become obsolete for many years.

The compression ratio of the spark ignition assembly is 7 : 1.

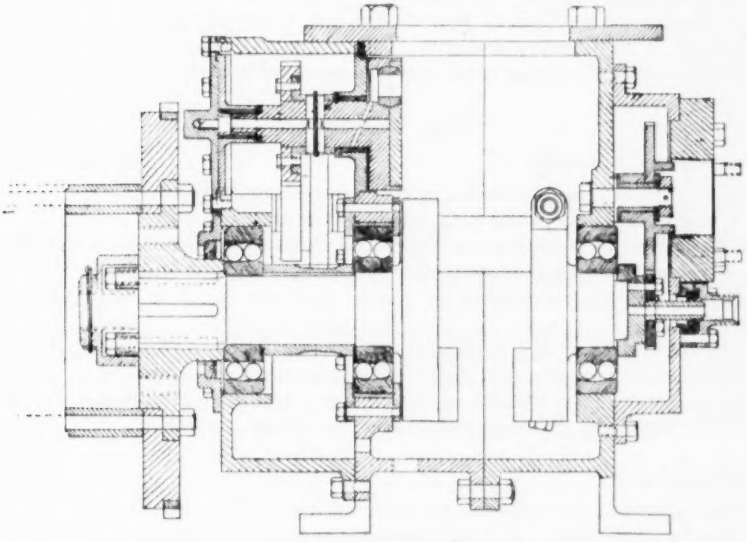


FIG 1

GENERAL ASSEMBLY OF CRANKCASE

The piston used for the compression ignition test is the Leyland piston with an increased height above the gudgeon pin to give a compression ratio of 16 : 1.

The Oil System

Two pumps are used, one fitted with a relief valve to control the oil supply pressure and the other being the scavenge pump.

The tubing used is made of lengths of stainless steel, except for two specified lengths of annealed copper tubing.

Brass elbows are used to avoid bending of the tubing so that a rotating bristle brush may be passed through each length of tubing.

The oil tank has a glass section so that the condition of the oil may be observed and oil consumption checked.

The system permits the easy measurement of the rate of circulation of the oil through the engine.

Measurements of the inlet oil supply pressure and temperature are made as close to the crankcase as possible.

All vents of the oil system and crankcase are connected via a filter box to a gas meter for measurement of the gas blow-by.

The Cylinder Assembly Cooling System

Air, supplied under pressure by a fan, is passed through a 3-ft straight length of ducting to a circular baffle which is fitted in an eccentric position to the cylinder baffle.

The position of the baffle is constant; the pressure of the cooling air across the cylinder assembly and the cooling air temperature are maintained constant. The direction and rate of flow of the cooling air are, therefore, constant, and the cooling conditions are repeatable from test to test.

Test Procedure

Cleaning and Assembly

The cylinder assembly is thoroughly cleaned and inspected.

A new piston and piston rings are used for each test.

The crankcase is washed and scrubbed in petroleum distillate and then in petrol, after which it is sprayed with enamel resistant to hot oil.

Care is taken in assembly to ensure that the big end clearances are standard.

The oil system is first washed in petroleum distillate, a rotating bristle brush passed through each length of tubing, and finally washed in petrol. This is essential if all traces of the previous test are to be removed, particularly when the previous test oil has contained silicones.

Running In

The oil system is filled with the running-in oil, which is a 12B Special.

After a short period of light running, the engine is run for a period of 5 hours at the following running-in conditions :—

	Spark ignition	Compression ignition
Engine speed, r.p.m.	2400	2000
Spark ignition or fuel ignition timing, ° BTDC	25	17
B.h.p. (approx)	15·0	7·7
Specific fuel consumption, lb/b.h.p/hr	0·5	0·42
Air intake temperature, ° C	Naturally aspirated	Naturally aspirated
Air intake pressure, inches Hg		
Cooling air temperature, ° C	33	33
Cooling air pressure, inches water	7	7
Inlet oil temperature, ° C	70	70
Inlet oil pressure, p.s.i.	70	70
Fuel	SPB.3	1D Caterpillar 1% test fuel

The engine is run at these conditions to prove that its condition is standard.

On completion of the running-in period the oil system is drained, and the engine is then ready for the test proper.

Test Conditions

The oil system is filled with 1½ gal of the test oil.

Steel and copper segments are placed in the oil system at its highest point where sludging and etching have been observed.

The engine is run at the following conditions :—

	Spark ignition	Compression ignition
Engine speed, r.p.m.	2800	2000
Spark ignition or fuel ignition timing, ° BTDC	25	17
B.h.p. (approx)	16·3	9·7
B.m.e.p. (approx), p.s.i.	133	110
Specific fuel consumption, lb/b.h.p/hr	0·50	0·43
Intake air temperature, ° C	34	34
Intake air pressure, inches/Hg	30	30
Cooling air temperature, ° C	33	33
Cooling air pressure, inches water	7·0	7·0
Cylinder temperatures (piston zone SAE 30), ° C	112	105
Inlet oil temperature, ° C	100	100
Inlet oil pressure, p.s.i.	43	43
Fuel	SPB.3	1D Caterpillar 1% test fuel

The engine is run for a period of 7 hours and then allowed to stand overnight.

After replenishing the oil system, the period of running is repeated each day until observations indicate that ring sticking has occurred, or a total of 27 hours running at test conditions has been completed.

Ring sticking is indicated by a rise in the rate of gas blow-by, a fall in power, and a rise of the piston zone cylinder temperatures.

Gas blow-by is the most definite indication of ring sticking. It usually increases steadily over a period of a quarter of an hour, but, in some cases, the increase occurs within a few minutes. Power falls and temperatures rise at the same time. Small temporary decreases in power and rises in temperature are observed prior to the increase in gas blow-by and indicate incipient ring sticking.

Observations Recorded Half-hourly :

Engine speed
Dynamometer load
Fuel consumption
Cooling air temperature and pressure
Inlet oil temperature and pressure
Rate of oil circulation
Rate of oil consumption
Rate of gas blow-by
Head of froth on the surface of the oil in the supply tank
Aeration of the oil in the supply tank
Cylinder barrel temperatures

On termination of the test, the engine is allowed to cool before being dismantled and examined.

Particular attention is paid to the freedom, or otherwise, of the piston rings, engine deposits, the condition of all phosphor bronze components, the big-end bush, and any abnormal features which may be observed.

The condition of the oil system and the metal segments is also observed.

Appraisal of Test Data

The engine is sensitive to the effect that some additives have on the piston rings which prevent their acting as efficient seals, with consequent increase in gas blow-by and oil consumption. This leads to overheating of the piston, which increases the internal friction of the cylinder assembly and reduces the effective brake horsepower. The engine loses speed; cylinder temperatures then decrease and the engine recovers. With some additives this condition may occur frequently during the initial period, becoming less frequent and eventually disappearing. The effect is dependent on the additive, its concentration, and the base oil. In some cases the test has to be abandoned.

It should be pointed out that all additives do not give rise to this condition, and it is never experienced with uninhibited oils.

Frothing and aeration of the oil are considered as characteristics that may need correction and, if necessary, an anti-frothing additive is added to the oil to reduce excessive frothing and for aeration. The additive is not added until it is seen that these characteristics of the oil are not going to reduce with changes in the composition of the oil produced during the course of the first period of the test. Frothing and aeration increase with lower viscosity due to the more rapid rate of oil circulation, but oils of comparable viscosity at test conditions vary in these characteristics, particularly when an additive is present. Frothing and aeration of most oils decrease as the test proceeds, but an oil has been tested where the converse was experienced.

Ring sticking is the paramount characteristic of the test. The ability of an oil to maintain engine efficiency is of the utmost importance. The period of running which may be obtained with uninhibited oils varies with the base oil. The viscosity has a pronounced effect.

The lower viscosity oils give an increase in the rate of oil circulation and an increase in the rate at which oil is thrown on to the piston. This increase in the rate of oil thrown on to the piston extracts more heat from the piston and lowers the piston temperature and extends the duration of the test. The majority of oils tested are in the SAE 30 classification, and the duration of a test of uninhibited oils in this classification is 9 to 11 hours. With two reference oils " A " and " B " the duration of test was 9 to 9½ and 11 to 11½ hours respectively.

Piston deposits are observed, but these are not given undue importance. Deposits will have no effect on the rating of an oil which prevents the sticking of the piston rings and maintains the efficiency of the engine. All oils of the SAE 30 classification, whether inhibited or not, give pistons which are lacquered, but although additives are not able to prevent the lacquering, they are able to keep the piston rings completely free.

The lacquering is less with oils of lower viscosity, and with an uninhibited SAE 5 oil the lacquering of the piston skirts is prevented, this being due to the lower temperatures of the piston skirts. The absence of lacquering on the skirts with the lower viscosity oils does not prevent ring sticking, although the duration of the test is extended.

Phosphor-bronze components are examined for any effect which the oil may have upon them. This is particularly so in the case of the gudgeon pin bush. The spark ignition test conditions produce higher temperatures, and

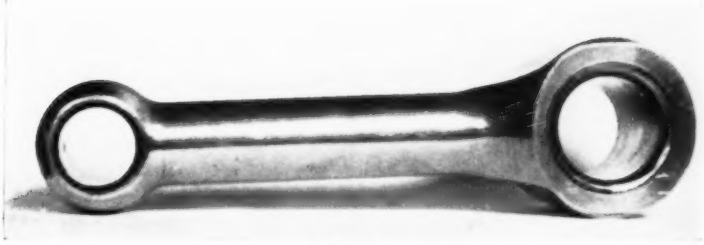


FIG 2

CONNECTING ROD

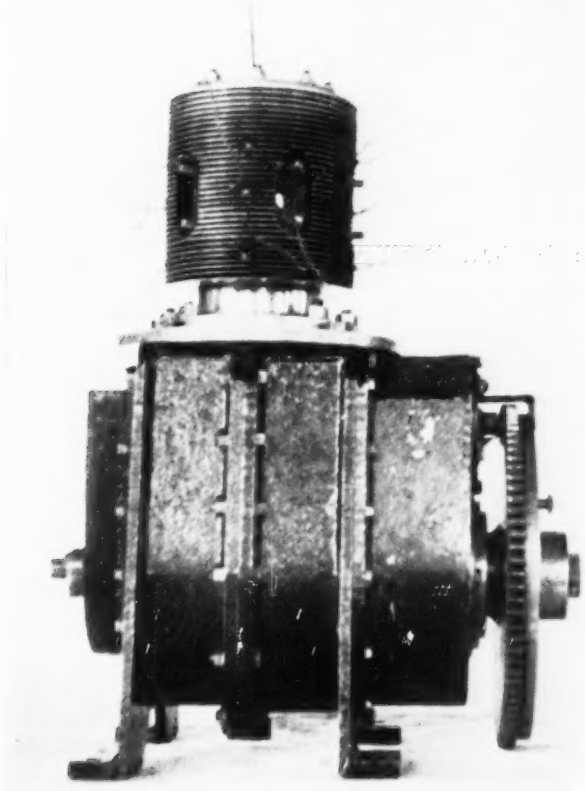


FIG 3

THE BLOGRO ENGINE

[*To face p.* 636.

FIG 4
SLEEVE VALVE

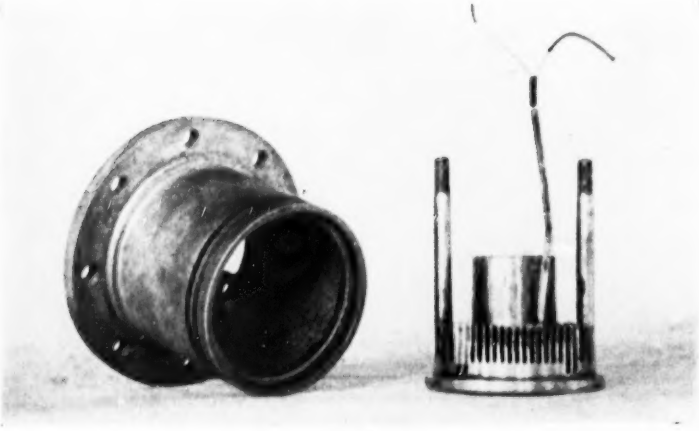


FIG 5
JUNK HEAD

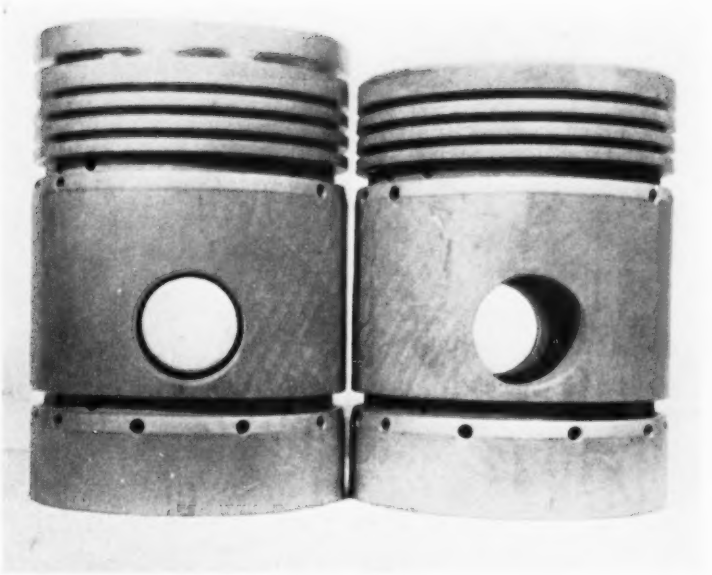


FIG 6

COMPRESSION IGNITION AND SPARK IGNITION PISTONS

FIG 7

PISTON AFTER 11 HOURS SPARK IGNITION USING OIL "B" (UNINHIBITED SAE 30)

FIG 8

PISTON AFTER 27 HOURS SPARK IGNITION USING OIL "B" PLUS ADDITIVE

FIG 9

PISTON AFTER 25 HOURS SPARK IGNITION USING OIL "C" (UNINHIBITED SAE 5)

FIG 10

PISTON AFTER 9 HOURS COMPRESSION IGNITION USING OIL "B" (UNINHIBITED SAE 30)

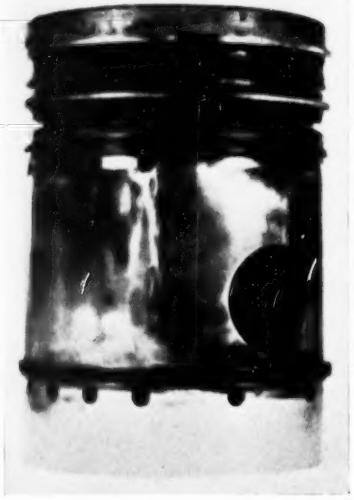


FIG 11

PISTON AFTER 27 HOURS COMPRESSION IGNITION USING OIL "B" PLUS ADDITIVE

the rate of any attack on the gudgeon-pin bush is accelerated. The phosphor-bronze bush is blackened and, on non-running surfaces, a roughened surface is produced. This attack is observed only when some inhibited oils are tested. In service, the attack on phosphor bronze is serious.

The big-end bush is examined, but no effect has been observed except with copper–lead bushes when test oils are those which attack phosphor bronze. This is not surprising in view of the well-known British engine manufacturer's experience of the use of copper–lead bearings with uninhibited oils for many years without corrosion troubles.

The metal segments show a variation in condition with different oils, although the condition is repeatable. The copper segment is seldom affected, but the steel segment can be coated with sludge and etched. The segments are prepared, cleaned, and then placed at the top of the oil system. They are not in the oil stream, and are only in touch with oil mist and gas blow-by vapours. Their position is cool.

During the test development work, an inhibited oil was used, and no effect on the mild steel end plate of the oil circulation measuring cylinder was observed. When the uninhibited base oil was used, the steel plate was covered with sludge and etched. The condition of the mild steel adaptor plate on the rear cover is similar to that of the steel segment. The condition is not yet considered significant, but it may be a pointer to crankcase corrosion.

Wear is not assessed. Wear of some piston rings is measurable, but it is very slight. It is felt that it is difficult to assess the " wear " characteristics of an oil by short laboratory tests. Wear, in service, is affected by the conditions of use, and the rate of wear is not consistent throughout the life of the engine.

Sludging, when the engine is run under spark ignition conditions, is insignificant, and has not yet been found to vary with the oil.

The rating of oils is as follows :—

(1) *Test hours completed without ring sticking :*

$$\text{Percentage rating} = 4(n - 2)$$

n = test hours completed.

(2) *Condition of bearings :* Any attack on bearings is undesirable. The attack is on the phosphor bronze and copper–lead bearings and, when present, is heaviest on the gudgeon-pin bush.

(3) *Condition of piston and rings :* Sticking of the rings is of first importance. The angle of sticking is of no consequence. Deposits are observed, but do not affect the rating of the oil.

(4) *Cleanliness of crankcase and oil system :* This is recorded in so far as it varies from that observed with the uninhibited reference oils.

(5) *Frothing and aeration :* This is recorded and the oil treated with an anti-frothing additive to bring these characteristics to normal proportions.

THE DEVELOPMENT OF AN INEXPENSIVE ENGINE TEST FOR EXAMINING THE BEARING CORROSION AND DETERGENCY ASPECTS OF ADDITIVE LUBRICATING OILS

By C. O. R. BELL * (Associate Fellow)

SUMMARY

The paper describes the development of a small scale engine test, primarily designed to correlate with the Chevrolet test on bearing corrosion, but which has also been shown to give valuable preliminary information on detergency. The engine selected has the advantage of low initial cost, and requires a minimum of modification. A number of these engines, suitably instrumented from a central position, allow a large number of tests to be carried out on experimental oils at a much lower cost than is possible using the full-scale recognized American test engines. The paper includes details of a statistical programme of tests which aim to show the degree of repeatability and reproducibility of the test. A graph is included illustrating the correlation obtained to date with the Chevrolet L.4 test.

INTRODUCTION

IN the development of new lubricating oil additives, the tests used in the development work must of necessity bear some relationship to the full-scale tests used in the principal specifications of the finished oils in which the additives are to be used. The cost of using these full-scale specification tests in the development of new products in their early stages is obviously prohibitive, and it is well known that, as yet, there are no laboratory bench tests which will predict faithfully the performance of these complex organic chemicals in internal combustion engines in practice, or in the laboratory dynamometer engine test. The need is apparent for an intermediate engine test which will not demand a high initial capital expenditure or take up a lot of laboratory space, but will permit a large number of experiments to be performed, the results of which can be applied later to the full-scale specification tests when the results of the engine screening tests indicate that the experimental product warrants it. This theme was borne in mind during the development of the engine test described in this paper. The test utilizes the Petter W.1 engine of 3 b.h.p. at 1500 r.p.m. with certain modifications. This Petter W.1 test is the first step in the scheme of development of a new oil additive, and it is intended to predict the performance of the additive in the Chevrolet L.4 test in respect of copper–lead bearing corrosion. The piston temperature conditions have been arranged so that the full rating scale of 0 to 10 is available between the piston skirt lacquer ratings of straight mineral oils and oils of Supplement I quality. This rating gives valuable preliminary information on detergency, and in the second step of development this information is checked on a small scale diesel screening test which utilizes a Petter AV.1 laboratory engine. These two tests are

* Monsanto Chemicals Ltd.

complementary to one another in deciding if an oil blend is likely to pass a certain specification on the Chevrolet and Caterpillar engines, but this paper will be restricted to a discussion of the Petter W.1 test.

Engine Selection and Modifications

The Petter W.1 3-b.h.p. engine was selected for the development of a bearing corrosion test because it has a low first cost, robust construction, and is easily adaptable for laboratory requirements. Another great advantage is that it has identical base fixing holes, shaft centre height, and crankshaft diameter to the Petter AV.1 laboratory engine. Thus, a design for an installation of four each of these two engine types can be made extremely flexible, since the engine beds may be adjusted to receive either engine. This has proved to be useful when the test programme on hand demands, say, a reduction in the number of diesel engines on the beds and a corresponding increase in the number of petrol engines.

The first modification of the engine was to supply a lubrication system permitting a much smaller quantity of oil to be used than that for which the engine was designed. The normal capacity of the sump is $6\frac{3}{4}$ pints, which would take too long to deteriorate under reasonable engine conditions, so the system illustrated in Fig 1 was adopted. This is somewhat similar to the Chevrolet lubrication system, and allows the engine to run satisfactorily on only 1 pint of oil, although 2 pints was adopted for the final procedure. The serrated oil pick-up trough allows the pump to draw oil from a very shallow depth, but over a wide area, thus preventing vortexing and consequent loss of oil pressure due to air locks in the pump. The pump supplies the oil to a trough fixed in the sump, so that the normally fitted connecting rod dipper received a constant depth of oil irrespective of the quantity in the sump. The oil is fed to the trough through a small orifice plate, and pump pressure is regulated to 9 p.s.i., thus ensuring a reasonably constant oil supply. During the early experiments considerable trouble was experienced with the melting out of the white metal main bearings at high oil temperatures, but this was overcome by fitting a separate oil feed to each main bearing externally through small diameter copper pipes. It was found that this reduced the temperature of the main bearing shells from the region of 230° C to a consistent 115° C. The main bearings now give several hundred hours life when operated at a sump temperature of 138° C.

In order to reproduce the high oil temperatures which are attained naturally in the L.4 test it was found necessary to fit electrical heaters under the sump. This was done by machining the bottom of the crankcase and clamping on suitable ring elements. The oil temperature is the most critical variable, and to obtain a temperature control of $\pm 1°$ C or better, a 1200-watt element was fitted under the sump, and controlled by a Simmerstat. A further 350-watt tubular element was fitted inside the sump, and controlled by a sensitive thermostat (also fitted in the sump) through an electronic relay.

In the Chevrolet engine certain of the metal parts, such as the crankshaft, connecting rods, etc., attain temperatures in excess of those reached by the corresponding parts in a single-cylinder engine, because of the greater heat

release per unit volume of the engine, and because the single-cylinder engine has a proportionally greater external surface area to dissipate the heat released. In order to provide a similar condition in the Petter engine, a " hot-spot " was provided by fixing a 225-watt heater on the pressed steel crankcase door. A thermocouple was also fixed in the inside surface of the door, and the temperature of this surface is controlled at 200° C. The position of the crankcase door is such that the oil thrown by the connecting rod dipper falls on to this hot surface in close contact with the oxygen in the crankcase atmosphere. This materially assists in breaking down the oil, and brings the used oil analysis after 36 hours' operation much closer to that obtained from the same oil test in the Chevrolet.

An evaporative cooling system was provided which would allow any jacket temperature between 100° and 190° C to be used by suitably mixing ethylene glycol and water in various proportions.

Specially Made Parts

The standard of accuracy of most of the production spare parts was found to be satisfactory, but in order to ensure that the minimum variation in limits and tolerance is obtained in the parts which have a direct effect on the accuracy of the test, the co-operation of piston manufacturers was sought and obtained. Sufficient pistons and rings were made in one continuous production batch to cover two to three years' testing. Allowance was made in the ring side clearance for the high temperatures at which the pistons were to operate, so as to avoid any ring sticking which might affect the lacquer ratings. The ring design was slightly modified in order to achieve a rapid bed-in and stabilization of oil consumption.

The Petter W.1 engine normally employs babbit-lined thin-wall bearings and a soft crankshaft. By arrangement with the bearing manufacturer special 60/40 copper–lead bearings were made, the wall thickness being decreased to give the bearing clearance normally employed with copper–lead. These bearings were used in the early tests direct on to the normal crankshafts, and although the crankshaft life was shorter than with babbit bearings, it was not uneconomically so. Later, however, the crankshaft supply position became difficult, so the used shafts were ground down by 0·005 inch, and built up to standard size with hard chromium plating. This improved crankshaft life considerably, and did not affect the amount of bearing corrosion obtained on the reference oil, when the crankshaft was fully run-in.

Test Procedure Development

The test conditions first tried approximated to those used in the L.4 test, the oil temperature being the same at 137·5° C; the jacket temperature was raised to 100° C so that distilled water could be used in the evaporative cooling system. Speed and load were 3·3 b.h.p. at 1500 r.p.m., which is 10 per cent above the full rated load of the engine. These conditions gave an adequate amount of corrosion of the copper–lead bearings, but the piston rating on a good quality straight mineral oil was better than 8. It was considered that to be most useful, the test should give piston lacquer ratings which utilized as much of the available range of 0 to 10 of the rating scale.

To achieve this, a much higher jacket temperature was found to be necessary and it was realized that the deposits formed at these temperatures could not be expected to correlate with the varnish ratings given by the Chevrolet engine. It was found after a number of experiments that a jacket temperature of 150° C would give a range of piston ratings from 2 to 4 on good quality straight mineral oils, 4 to 6 on premium type oils, 7 to 8 on 2-104B oils, and 9 to 9·3 on MIL-0-2104 type oils. It was also found that the undercrown ratings were more useful than the piston skirt ratings on repeatability in the upper range from 8 to 10.

A number of experiments were carried out to see the effect of reducing the oil charge in the sump from 2 pints to 1 pint. It was found that the total bearing weight loss was considerably increased and that the used oil analysis after test was almost the same on viscosity increase and neutralization number as the analysis obtained on the same oil after test in the Chevrolet engine. The repeatability of the bearing corrosion was, however, found to be much poorer with the reduced oil quantity. At a high rate of bearing weight loss in the final hours of the test it is thought that the formation of varnishes or deposits on the bearing shell materially affect the final weight loss according to the rate of formation of such deposits. This only applies to highly corrosive base oils, and not, of course, to inhibited oils of low corrosion. This point is illustrated in the results of the statistical programme.

TABLE I

Final Test Conditions of Petter W.1 Oxidation Test

Engine speed, r.p.m.	1500 ± 15
Engine load, b.h.p.	3·3 ± 0·1
Sump oil temp, ° C	137·5 ± 1
Oil pressure, p.s.i.	9 ± 1
Operating time	36 hours, continuously or in 4 periods of 8 hours and 1 period of 4 hours
Coolant temp (inlet), ° C	148 ± 2
Coolant temp (outlet), ° C	150 ± 1
Spark advance	20° ± 1° BTDC
Spark plug gap, inch	0·025
Contact breaker clearance, inch	0·015
Oil capacity, pints	2
Oil make up	4 ozs new oil at 16 hours
Fuel	PE/IP spirit
Exhaust temp, ° C	480 to 520
Hot spot heater plate temp, ° C	200 ± 2

It was decided that it would be better to get a lower weight loss value from the uninhibited oil of good repeatability than a higher value of poorer repeatability. The test conditions in Table I were therefore adopted as standard and written into the final test procedure.

DISCUSSION OF RESULTS OBTAINED WITH THE PETTER W.1 OXIDATION TEST

It has been found that the amount of bearing corrosion obtained with this test is approx one-tenth of that obtained with the Chevrolet L.4 test. The difference in bearing area accounts for a factor of 1·7 : 1; the remaining difference is partly due to the fact that the oil does not deteriorate to quite the same extent as in the L.4 test (the 2 pints used representing approxi-

mately twice as much oil per square inch of swept cylinder wall area as in the L.4 test), and partly due to the difference in the metallurgical structure of the two types of copper–lead bearing. In spite of this, however, the test has shown itself capable of rating oils in the same order as the L.4 test, and an expression has been derived which enables Chevrolet L.4 copper–lead bearing weight losses to be estimated from Petter W.1 bearing weight losses and limits established within which this estimate would prove reliable. In practice there has not been a case to date where a definite pass indicated by the Petter W.1 test has resulted in a failing L.4 test. The reverse, however, is not quite true, as there have been several cases where a possible fail has been predicted (assuming the relationship between the tests is linear), which have in fact subsequently passed the L.4 test. This might be due to the combined inaccuracies of the two tests, or it might suggest that the Petter W.1 test is more sensitive in the lower range of bearing corrosion than the L.4 test, thus giving rise to a non-linear relationship. For the time being, however, it has been assumed that the relationship is linear, and a graph showing the correlation obtained to date with the L.4 test is given in Fig 7. The exact equivalent of 200 mg on the L.4 test, which is generally accepted as being the maximum allowable in most lubricating oil specifications, is seen to be 25 mg, but on the evidence of correlation obtained so far, this figure may go up as far as 50 mg and a passing L.4 test may still be obtained once in every twenty cases, as will be seen from the upper 2σ limit. In practice it has been found safe to interpret the test as indicating a definite L.4 pass if 25 mg or less is obtained, a possible pass if the result is between 25 and 40 mg, and a probable fail if 40 mg or more is obtained. Experience has been gained on nearly 200 36-hour Petter W.1 tests to date, and further evidence is being collected to strengthen the reliability of this interpretation and if possible to narrow these limits.

Application of the Petter W.1 Test

The Petter W.1 test was primarily developed for use as a screening test in the development of new materials as bearing corrosion inhibitors, or in assisting the improvement of plant processes in the manufacture of existing products. It has been found to be particularly useful in developing bearing corrosion response curves of different additives, made for instance by different processes, in a standard base oil, or for obtaining the response curves of a particular additive in different types of base oils. To carry out such determinations in the full scale Chevrolet L.4 test would obviously be very expensive, but the relatively low cost of carrying out a series of tests at different additive dosages in the Petter test has made it worthwhile, especially since the curves may be converted into terms of the L.4 test later if so required by the use of the relationship previously mentioned.

Fig 2 illustrates the type of response curves that may be obtained. It will be noticed that additives A and B are very similar in base oil I, while additive C is very much more responsive at the lower dosages. Additive A is also very much more responsive to base oil II, and the curve indicates that only 0·15 per cent of additive A is required to give complete protection from copper–lead bearing corrosion, while 0·55 per cent is required in base oil I. This sort of background information is very useful, and to obtain it

in such detail on the L.4 test would not only be expensive but also time-consuming due to the extra engine building time on the six-cylinder engine.

The employment of a jacket temperature of 150° C outlet by the use of a constant boiling-point mixture of ethylene glycol and water gives piston skirt and undercrown ratings which cover a large proportion of the usual rating scale range of 0 to 10, between the worst straight mineral oil experienced and oils of Supplement I quality. While it is admitted that no gasoline engine test can reproduce variations in results which are solely due to factors peculiar to diesel engine operation (*e.g.*, variation of diesel fuel sulphur content, carbon residue, etc.), the gasoline engine test can broadly classify detergency relatively as a diesel engine would when comparing two oils, all other conditions being equal.

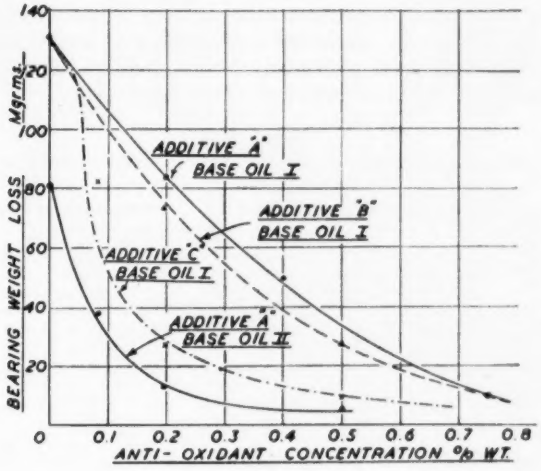


FIG 2

COPPER–LEAD BEARING WEIGHT LOSS RESPONSE CURVES

The piston skirt ratings from the Petter W.1 test have proved useful in this respect, particularly in the preliminary evaluation of an unknown base oil. The test not only gives the degree of potential corrosivity of the oil, but also indicates its general oxidation stability from the used oil viscosity increase figures and neutralization number. The piston skirt rating gives an idea of the deposit forming tendencies of the oil, and together with the oil ring rating an assessment of the detergent requirements to reach a certain standard may be made. A single Petter test on the base oil, therefore, helps considerably in determining the likely balance of anti-oxidant to detergent. The preliminary formulation may then be tested by a further Petter W.1 test, and if satisfactory it can go forward for test on the Petter AV.1 diesel engine screening test. A satisfactory result would then indicate that the formulation is ready for full scale evaluation on the Chevrolet L.4 and Caterpillar L.1 engines if an approval is the ultimate aim. It is not always necessary to follow all these steps in the screening procedure, as if

the first Petter W.1 test on the base oil indicates that a base oil with similar properties has been fully tested before, it is often possible to eliminate one or more of these steps. This serves to show the part played by the Petter W.1 test in the complete procedure.

The test is also useful in classifying a reference oil which may be submitted to the laboratory and which has to be matched by treating a certain base oil with suitable additives. Fig 3 shows the set of piston standards used in rating the test pistons, and indicates the range covered by each particular recognized oil type from which they were obtained.

Statistical Programme

In developing a new test of this nature it is obviously very important to know at an early stage to what extent the test can be relied upon to give information upon which important decisions can be made. This can normally only be done by accumulating much data over a considerable period by testing oils which have previously been tested by another method of known reliability. It is unfortunate that the expense and duration of

Table II

Summary of Results from Petter W.1 Statistical Programme

Engine no.	Solvent-refined straight mineral oil				Reference oil REO-7-48			
	Test no.	Bearing weight loss, mg	Piston skirt rating	Under-crown rating	Test no.	Bearing weight loss, mg	Piston skirt rating	Under-crown rating
1	11	64·2	3·5	4·2	5	12·6	8·0	8·5
1	16	71·5	3·4	4·2	14	7·4	8·7	9·3
2	2	94·7	4·3	4·5	6	14·8	8·5	8·6
2	13	70·9	4·0	4·5	9	8·7	8·7	9·2
3	1	61·2	1·5	2·0	4	7·5	8·8	9·0
3	12	97·6	3·7	4·0	8	7·0	8·8	9·0
4	3	72·8	3·6	3·8	7	12·2	8·4	8·3
4	10	66·9	3·6	4·6	15	13·3	8·3	8·6

lubricating oil tests make it impracticable to run a monthly correlation scheme such as is so effectively and so simply run in the case of fuel testing engines. How much simpler would be the task of the lubrication engineer and how much more confident he would be of his results if this were possible! There is, however, one short cut possible in the case of a lubricating oil test which is not basically too expensive, and that is the employment of statistical methods.

It was decided that, if the Petter test was to be really useful at an early stage of its development, it would be desirable to know the reproducibility and repeatability of the test. Duplicate tests in the early stages did help towards this, but they did not indicate where the differences arose and how much of the difference was attributable to each variable. It was decided therefore, to carry out a complete programme with the sole object of obtaining information on the test's capabilities and reliability. It was decided

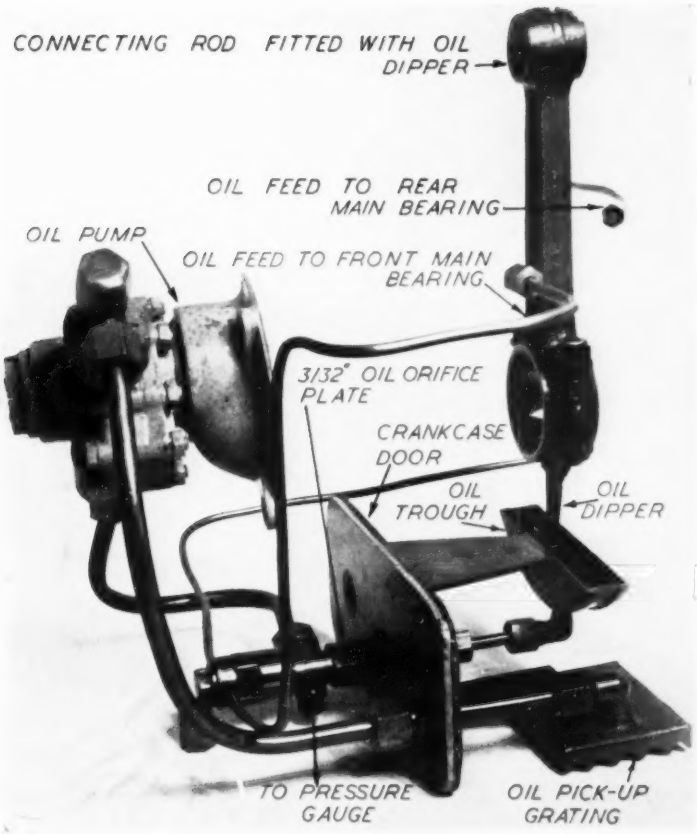


FIG 1

PETTER W.1 LUBRICATION SYSTEM AS MODIFIED FOR OIL TESTING

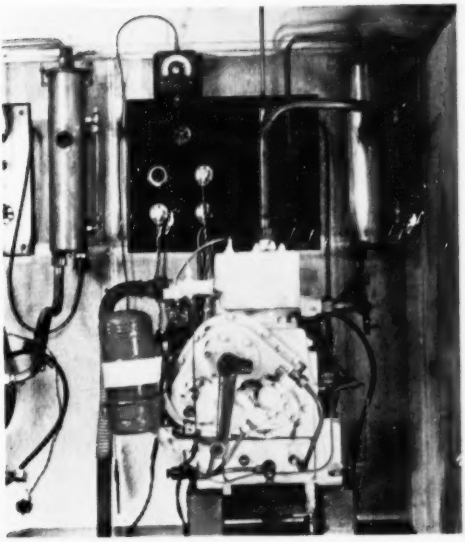


FIG 4

FRONTAL VIEW OF PETTER W.1 MODIFIED AS A TEST ENGINE

[*To face p.* 644.

1 2 3 4 5 6 7 8 9 10
STRAIGHT MIN. OILS
PREMIUM OILS
2-D 4-B OILS
MS-D-2104 OILS
PISTON SKIRT RATINGS
1 2 3 4 5 6 7 8 9 10
PISTON UNDERCROWN RATINGS

FIG 3

RANGE OF PISTON SKIRT AND UNDERSKIRT STANDARDS SHOWING THEIR RELATIONSHIP TO VARIOUS TYPES OF LUBRICATING OILS CLASSIFIED BY DETERGENCY

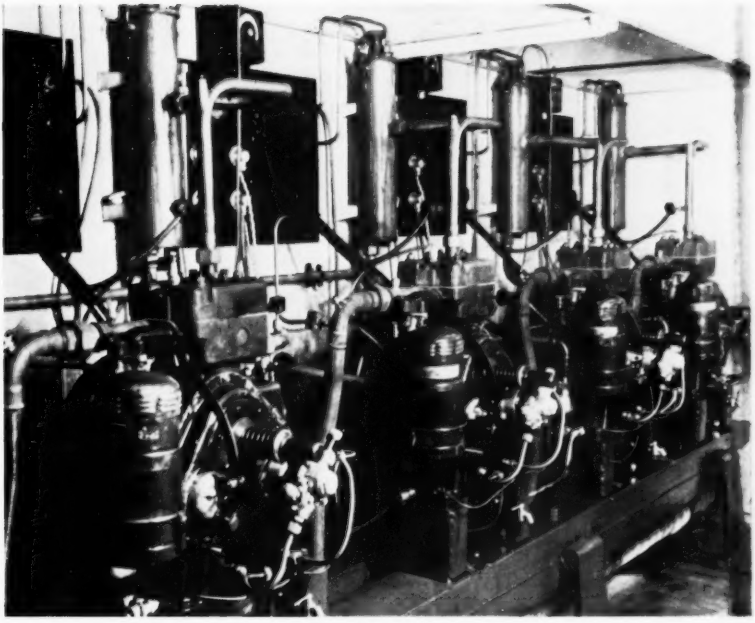


FIG 5

GENERAL VIEW OF INSTALLATION OF THE FOUR PETTER W.1 ENGINES SHOWING SPACE ECONOMY

FIG 6

INSTRUMENT PANEL USED WITH THE PETTER W.1 ENGINES AND ALSO FOUR PETTER AV.1 DIESEL ENGINES

The control panels for the Chevrolet L.4 and Caterpillar engines are seen in the background.

FIG 8

COMPLETE SET OF PISTONS FROM THE STATISTICAL PROGRAMME

eventually to limit the programme to determine the variability between two oils, one of high and one of low corrosion, the oils being selected to give low and high piston ratings respectively. The variability between four independant engines was to be determined, and also the variability within engines. This required a minimum of sixteen engines tests, as each oil had to be tested in duplicate on each of the four engines. The order in which the tests were carried out was randomized to eliminate any systematic error. Table II gives a summary of the results obtained on the three principal criteria produced by the test, namely piston skirt rating, under-crown rating, and copper–lead bearing weight loss, which is accepted as a measure of bearing corrosion.

The actual order in which the tests were carried out are summarized in

TABLE III

Randomized Order in which Tests were Carried Out

Engine I	5, 11, 14, 16
Engine II	2, 6, 9, 13
Engine III	1, 4, 8, 12
Engine IV	3, 7, 10, 15

Table III, which gives the respective order for each engine. The chronological order in which the whole programme was carried out was the same as the numerical order given.

STATISTICAL TREATMENT OF RESULTS

The analysis of these results follows the well-known technique known as the "analysis of variance," which is described in any elementary statistics textbook.[1,2] In applying this, the variation between the two oils is compared with the variation between the tests on the same oils. This latter variation may be split up into the variation between engines and that within engines. From the variation of the tests on any one oil, the magnitude of differences, which may be regarded as significantly different from it, may also be estimated. It is not intended that this paper should give in detail the derivation of results from this programme, so the following summary of conclusions is presented with explanations of their significance.

SUMMARY OF STATISTICAL ANALYSES AND THEIR INTERPRETATION

Bearing Corrosion

(*a*) The variance between oils is significantly greater than the inaccuracy of the test (variance within oils). The test is therefore capable of differentiating between these oils.

(*b*) The variance between engines is no greater than the variance within engines, so that the inclusion of several engines does not appear to add to the variability of the test.

(*c*) In the low bearing-corrosion range a difference in bearing weight losses between two oils of more than 10·8 mg on single tests indicates that the oils are significantly different at the 95 per cent probability level. In other words, it would be correct to assume that two oils differing by more than this amount were in fact different in their tendency to corrode copper–lead bearings under the Petter W.1 test conditions in nineteen cases out of

twenty. If the result of a single test is compared with the mean of a set of eight tests as in the statistical programme, the significant difference becomes 7·8 mg.

(*d*) In the higher bearing corrosion range, the significant difference at the 95 per cent probability level was 45·7 mg.

(*e*) Consideration of the results of practical importance, *i.e.*, those contained in the box (Fig 7), indicates that the "discriminating power" of the Petter test is about 2½ times as great as that of the Chevrolet test. Here "discriminating power" is defined as the ratio of the variance between oils to that within oils.

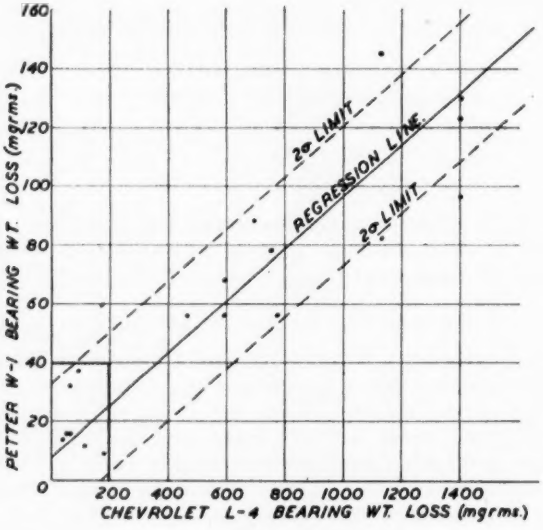


FIG 7

DEGREE OF CORRELATION TO DATE BETWEEN PETTER W.1 BEARING CORROSION TEST AND CHEVROLET L.4 TEST

Piston Skirt Rating

(*a*) In the higher detergency range (above 2-104B level) the significant difference which would indicate a difference in lacquer forming tendencies between two oils was 0·70 piston ratings.

(*b*) In the lower detergency range (or rather no-detergency range !) this difference was represented by 2·1 piston ratings. It will be seen, however, by reference to Table II that this wide difference is almost entirely due to one result, namely Test No. 1. A reason was sought for this anomaly, and eventually by comparison of the engine wear measurement records, it was found that in this test alone in the whole series the total wear in the cylinder bore was on the upper limit of 0·004 inch, which was at that time the maximum above which cylinders were normally scrapped. Further analysis of the records produced other examples where cylinders worn above 0·003 inch produced low piston ratings in the low detergency range. The Petter W.1 test method has therefore been modified to exclude cylinders worn above

0·003 inch over standard size. A previous independant test had been carried out on the same straight mineral oil as used in the statistical programme using a cylinder which has a maximum wear of 0·0015 inch above standard which gave the following results :—

Piston skirt rating . . .	4·0
Undercrown rating . . .	4·7
Bearing weight loss . . .	62·7 mg

If this test is substituted for the obviously erroneous Test No. 1, the significant difference for piston skirt rating then becomes 0·77 piston ratings in the low detergency range. It should be noted that the bearing weight loss in Test No. 1 was not significantly affected by the cylinder condition which gave rise to the erroneous piston ratings, as would be expected.

Undercrown Ratings

(*a*) In the higher detergency range the significant difference for undercrown ratings was 0·90 piston ratings.

(*b*) In the lower detergency range the significant difference was 2·1 piston ratings including Test No. 1, or 0·78 piston ratings substituting the test mentioned for Test No. 1, which was also obviously erroneous in respect of undercrown rating.

A visual comparison of all the pistons resulting from the statistical programme is given in Fig 8, including the substitute test.

Correlation Between the Petter W.1 Test and the Chevrolet L.4 Test

As mentioned earlier in the paper, of the two hundred tests carried out up to the time of writing, nineteen have a direct connexion with the L.4 test, as exactly the same oil blend has been tested in the Chevrolet engine. These oils cover a wide range of different base oil types and different additive types and concentrations, and, based upon these results, the Petter W.1 test has been found to give a promising degree of correlation directly with the L.4 test. These results have also been subjected to statistical examination, and it has been found that the correlation coefficient, which is a statistical measure of the degree of association, is 0·926, indicating good correlation on the results so far obtained. The line of best fit to predict L.4 test results from Petter test results is found to be :—

$$\text{(L.4) result} - 600 = 11{\cdot}11 \times (\text{Petter result} - 61{\cdot}5)$$

This line accounts for 85 per cent of the variation of results, and its position is shown in Fig 7. The 2σ limit lines which are also shown theoretically include about 95 per cent of the likely readings. The positions of these limit lines are calculated by finding the residual variation about the regression line, but it is assumed here that the variation is the same at both high and low rates of corrosion. In practice, as the results of the statistical programme have shown, the test is more accurate at the lower end of the bearing corrosion scale than at the upper end. It is, therefore, probable that these limit lines should be closer together at the lower end and wider at the upper end of the scale than shown in Fig 7.

As a " go " or " not go " test for measuring the degree of protection

against copper–lead bearing corrosion given by a particular inhibited detergent oil, it is the lower end of the scale which is of importance. While it is useful to know approximately the severity of corrosion caused by an unstable straight mineral oil, especially as a guide in estimating the amount of anti-oxidant necessary, precision at these high levels of corrosion is largely a matter of academic interest.

Cost of Engine Testing

The initial capital and installation costs and subsequent running costs of a particular test engine set-up may be considered to have a direct bearing on its eventual overall usefulness to the operating company. In all laboratories, with the exception of those which operate on an unlimited research budget, the cost of an engine test determines the total number of tests that may be attempted in a given period, or the number of tests they may justifiably be carried out in tackling a particular problem. This is particularly true when applied to engine tests for controlling plant production of additives, or testing finished lubricants on a pass or fail basis to a given specification. This aspect should be given considerable thought in adopting any new engine tests for quality control purposes. The considerations are entirely different for a research tool which must be completely versatile in its applications. The author is of the opinion that the average of two small single-cylinder engine test results is probably more significant than a single test result on a multi-cylinder engine which is three times as expensive to run. The single-cylinder engine is obviously easier to control as regards

Table IV

Comparative Direct Costs of Chevrolet L.4 Test and Petter W.1 Test

Chevrolet L.4 Test

	£	*s*	*d*
Fuel, 145 gal at 4*s* 1½*d*	29	18	1
Pistons and rings (assuming two written off each test)	4	0	0
Gaskets (one engine set)		10	11
Copper–lead bearings (four halves)	3	1	4
Depreciation per test on engine only (assuming total replacement in eighteen months, in which time thirty-six tests per engine would be performed)	3	6	8
Labour (including supervision):			
Operating	10	10	0
Engine building and test bed maintenance	20	0	0
Total (excluding overheads)	£71	7	0

Petter W.1 Test

	£	*s*	*d*
Fuel, 14 gal at 4*s* 1½*d*	2	17	9
Special piston		18	8
One set of rings		5	6
Sundry spares (average)	1	10	0
Depreciation per test (assuming total replacement in eighteen months, in which time forty-five tests per engine are performed)		12	0
Labour:			
Operating	3	2	0
Engine building and test bed maintenance	6	4	0
Total (excluding overheads)	£15	9	11

Chevrolet L.4–Petter W.1 direct cost ratio = 4·6 : 1.

the physical conditions of the test, and its total fuel consumption is a very significant cost factor in the U.K. Table IV gives some comparative figures for the cost of operation for the Chevrolet L.4 test and the Petter W.1 test described in this paper.

The above figures are based upon the experience gained in a laboratory which operates one Caterpillar, two Chevrolet engines used alternately on a single test bed, four Petter AV.1 diesel engines, and four Petter W.1 gasoline engines. The economy in operating labour achieved on the small test engines is brought about by the use of the common control panel, which enables one operator to look after all eight small test engines. The use of automatic temperature recorders and temperature controllers also reduces unnecessary labour costs. Figures for overheads have been deliberately omitted, because this will vary considerably from one laboratory to another. The inclusion of them would probably increase the cost ratio in favour of the small single-cylinder engine, because in a given time more individual tests can be performed (the tests being of equal length) due to the much shorter engine turnround and run-in time. In practice of course, the whole engine is not replaced in entirety after eighteen months' testing, the process is a continuous one, and the time stated represents an average replacement condition. In the case of the W.4 engine, the crankcase and lubrication system seem to be a permanency, the cylinder block, crankshaft, camshaft, gears, etc., are replaced as necessary, and this is coveredby the depreciation and sundry spares allowances. In the case of the L. 4 engine, the entire cylinder block must be discarded when the bores are worn, and the light gauge stamped steel parts do not stand up so well to frequent stripping and assembly as do the light alloy or cast-iron castings used in the Petter AV.1 and W.1 engines.

The author has tried to show, that it is possible to take a cheap and robust commercial engine and develop it into a useful tool for quality control and the screening of lubricating oil and additive blends. It is felt that with further development and standardization in conjunction with a parallel development and standardization of the Petter AV.1 diesel engine test, a possible low cost answer may result in the search for a British lubricating oil quality measuring instrument.

Acknowledgments

In conclusion, the author would like to thank the directors of Monsanto Chemicals Ltd., for permission to publish this paper. Special acknowledgment is due to P. D. Potts, also of Monsanto's Development Division, who was responsible for the design of the statistical programme discussed in the paper, and for the analyses of results, a summary of which was also given. Acknowledgment is also made to Messrs. Specialloid Ltd. and The Glacier Metal Co. Ltd., for technical assistance in the design and manufacture of the special pistons and copper–lead bearings used in the Petter W.1 test.

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[1] Ministry of Supply, "Industrial Experimentation," H.M.S.O.
[2] Tippett, L. H. C. "The Methods of Statistics," Williams and Norgate (London, 1941).

Discussion

Dr D. Clayton: This symposium will undoubtedly be valuable, because it contains so much information that has not previously been available. The ideas involved are not easy to acquire, and discussion of the subject has been characterized, not only by divergence of opinion, but by much argument. Reading these papers once and hearing opinions expressed in this discussion will not secure agreement. But one can visualize an inner cabinet of the people most concerned having a round table argument on the evidence so far presented, with the aim of agreeing on the main characteristics of the present situation. Unless some measure of this sort is taken, agreement will be deferred, and time will be wasted in talking and, indeed, in doing experimental work. If, however, there could be such a session, I believe there are many points on which agreement could be reached and future policy made plain; rational action could be secured within months, instead of allowing the argument to run on for years.

The outstanding lesson pointed by these papers is the need for *analysis* of the problem. Fortunately, Dr Kendall and Mr Richards's paper comes first in this group, and was preceded by Dr Kendall's paper in the January issue of the *Journal of the Institute of Petroleum*. This is a very clear statement, and there is supporting evidence in the other papers. Moreover, the accompanying papers in this group from Thornton give most valuable information on how this analysis can be carried out.

We were once very arrogant in thinking that a simple oxidation test could represent the complexity associated with lubricating engines. There could be little disagreement when eventually we came to accepting an engine test as necessary. It is, however, arrogant again on our part to think that a complex engine can be a satisfactory instrument for evaluation. The variables are far too great for it to serve for specific evaluations. There has been almost pride in insisting that it is only the engine that can give the answer; indeed, in these papers there is a repetition by many authors that an engine test is essential. Temporarily, yes, but ultimately, no. I believe that, eventually, we shall analyse the behaviour of oils in an engine sufficiently to allow us to simulate the specific properties required by using several pieces of relatively simple apparatus, and I find a number of these papers, *e.g.*, the ancillary hot spot of Mr Bell's paper, as showing this trend very clearly. We have to go through this phase of development, and it will be some time before we reach the laboratory apparatus stage. After all, it is a common feature of development of, for example, automatic machines, that the first stage is to try to do mechanically what the human hand does in manual operation. But such machines are never left in that stage: it is eventually realized what the essential features of the operation are, and the most appropriate mechanism for that operation is then devised. To use the analogy of steel testing given in Dr Kendall and Mr Richards's paper, it is clear that if the behaviour in, say, a pump is required, we do not now commonly set up a series of pumps and run them under various conditions to see how the steel behaves, as is being done here for engines; our faith in analysis is such that we think out what property of the steel is significant, and apply the laboratory test that represents it most nearly in the specification. It may not be glassware that will be

used in the eventual laboratory testing of lubricating oil, but I believe it will be relatively simple apparatus, such that there can be adequate control on the essential variables. Dr Kendall, in his paper in the *Journal of the Institute of Petroleum*, sets out at considerable length all the things that might happen and that have to be considered in the analysis of the problem, but I believe that it will be found that the number of serious factors is relatively small, and, if we do not strive to attain too great a precision too early, the number of critical tests will turn out to be reasonably small. This is clear from the experience with steels, for although there is still much to learn of the behaviour of materials, most needs are being met reasonably well.

In the Foreword to BS 1905 reference is made to the difficulty in seeing the way to British engines displacing the L.1 and L.4 tests; this is, in the light of these papers to-day, an unduly pessimistic assessment of the position. If we clearly recognize the virtue of analysis of the problem, and deal in a business-like way with the specific features with the most appropriate test engines, and then devise simple tests that will in turn do the same thing, we can repay to America relatively soon the debt we owe in this field.

We should not pay too much attention to the L.1 and L.4 tests, and certainly these new tests should not be distorted to agree with them. They are now necessary for commercial purposes, but we should boldly criticize them if they do not meet our needs, and substitute something better as quickly as possible. Mr Wilford and others all recognize that top scraper ring plugging is the common bus engine failing, and this is not met by the existing L.1 and L.4 tests. As is made clear in the Foreword to BS 1905, there is no finality about the specification; it can be revised, particularly where a clear improvement is proposed. But the alteration should be to make the tests even more specific, not to attempt to meet the common plea that *a* test must imitate practice more comprehensively.

There is theoretically no reason why one basic test engine, adaptable in a wide variety of ways to secure different engine conditions, should not be used. The BLOGRO engine is the only one like that described here; I have seen no mention of the Shell-Ricardo and Anglo-Iranian test engines. I presume that high cost precludes the adoption of such an engine. Such an arrangement for use over the years would have advantages, especially that of being able to keep many factors constant, and I should be interested to hear comments on the point.

Analysis of the problem has to be applied to the engines in service as well as to the oil test engines. I am paying this special attention, because engine manufacturers have even further to go than the oil people in assessing clearly their position in relation to lubricating oils. There has been too much blanket recommending, for example, of H.D. oils as a cure-all for troubles, or even as a means of securing better running, when in fact there is no current trouble. It is quite logical, even if some ring sticking or piston deposits occur, to refuse to use H.D. oils at increased cost, if overhaul is determined by factors other than lubricating oil deterioration—provided, of course, that the cost of cleaning is not greater than the extra cost of the lubricating oil. Also, an engine manufacturer, instead of declaring that his guarantee for an engine will not hold unless H.D. oils are used—and

this is often because an oil company persuaded him that they were necessary —should consider carefully what is the market for his engine. If the engine is varied in its uses, he should not issue a blanket recommendation, but should analyse under what conditions his engine may suffer from ring sticking, and should then not guarantee his engine under those conditions unless H.D. oils are used He will then, moreover, recognize weak points of design, and be in a position to improve his engines accordingly.

I have used the term " H.D. oils " in what I have just said in a conventional sense. I think we have now reached the stage of development at which we need to make some definitions, and only use terms of broader meaning when we are clear as to what they cover. It is evident from reading these papers that the authors use various terms with somewhat different meanings, *e.g.*, " detergent oil " is used with various shades of meaning.

I have dealt so far particularly with the analysis of the problems. In the early stages that means proliferation—an increase of variables and tests. But a few factors are particularly important, and they are the ones that will require specific testing. The field of lubrication of engines can never be a precise one—approximation is inevitably the order of the day. When the important factors are recognized, the oil supplier will inevitably round off in his formulation, and I see no reason for there being many grades of oil as a consequence—a few grades will be sufficient, but it will be clear what each will do and not do. The user, recognizing the same terms, will equally approximate in his selection of the type of oil that will meet his needs. This would provide the answer to one of Mr Wilford's pleas.

If one or two specific factors affect a particular user, I think it follows that he will use the particular engine or apparatus that tests that behaviour as his means of routine checking of supplies—a notable difficulty at the present time. I see no prospect of a comprehensive test serving this purpose.

M. Roegiers : Excessive engine wear is not only affected by " the combustion products of metal-containing fuel "—as one of the authors puts it—but also by the combustion products of the organo-metallic compounds which are contained in the so-called " additive oils."

Nobody questions that ring sticking is delayed by such additives when used with diesel engines which are running on bad fuel and under heavy load. However, the increased wear caused by additive oils, about which the users of diesel and gasoline engines increasingly complain, is to be attributed especially to the abrasive character of the " cleansing powder " formed by the ash (barium salts, calcium salts, etc) which results from the combustion of such oils. The many photographs of pistons in the various papers display the action of these cleansing powders, but they do not reveal the increase in wear of bearings, shafts, and even of cylinder liners. The artificial and misleading operating conditions of the L.4 test must be held responsible for this having been overlooked for so long. Facts of this kind point to the danger of having testing methods officially standardized by private or closed committees.

Let me further exemplify the argument. Electrically-treated base motor oils are unable to pass the MIL-0-2104 qualification tests, because they are caused by the L.4 test to show up—just like a straight mineral oil—40 or 60 times more bearing wear or corrosion than additive oils. Yet

these electrically treated oils yield the highest " point scores " on any other test spark ignition engine but the L.4. Bearing corrosion was never a problem with these oils, and they are world-reputed for providing lowest wear, exceptionally clean engines, and extended oil-draining periods, under various working conditions.

I hope that a rationalization of the MIL-0-2104 qualification tests will no longer prevent this class of motor oils entering into the picture.

J. G. WITHERS: Dr Clayton in the opening remarks asked why the Sunbury Shell-Ricardo engines were not included in this symposium. The Sunbury engine was not included, because it has been very fully reported on two previous occasions. We are using the engine for a wide range of test conditions, and others outside Sunbury are also using it. Its performance is very satisfactory, and correlation with many types of service duty has already been shown. As has been said, one engine test, and even one engine, cannot be expected to cover the whole field of engine testing.

I was particularly impressed by Dr Clayton's remarks when he said that our ultimate aim should be simple laboratory tests for evaluating the specific features of lubricating oils. I fear that this is an ideal which we shall never achieve. Twenty-five years ago I believed that we should soon be abandoning test engines for knock rating—after all, the very simple process of compression, firing, and noting whether the fuel knocked could, one would think, easily be reproduced in laboratory apparatus. We are still far from a simplified knock rating method.

I should like to raise a point on the first part of the paper by Dr Kendall and Mr Richards. At the end they say that the test engine should not be used as a means of simulating conditions in the field. I am not quite clear what they mean, because this seems to be just what the aim should be, although, of course, I would agree that it is impossible to simulate all field conditions in one test; but at least, one should try to simulate the conditions pertaining to the particular problem. Correlation between engines is clearly difficult to obtain, but it is most likely if the relevant operating variables match the field variables as closely as possible.

With reference to a later part of the paper, I am not sure that the specific characteristics of a lubricating oil are directly relatable to such factors as piston-ring sticking. These themselves depend on many variables, such as piston temperature, fuel quality, and catalytic effects. I think that the specific factors are the engine running conditions themselves, and that oils should be rated for any bad characteristics which they exhibit, under a particular set of running conditions.

I think the very short tests for piston-ring sticking, such as the Fowler test in the paper by Mr Atkinson and Mr Golothan, and the air-cooled engine test in the paper by Mr Perry, are too severe. Higher piston temperatures than normal are used to accelerate the oil breakdown and the formation of deposits, so that very short test times are obtainable. In the Fowler test, for instance, the piston temperature in the neighbourhood of the ring groove is given as 270° C, which is very much outside any automotive or industrial diesel operating engine conditions. The very short ring-sticking times obtained by these tests are evidence that the conditions are too severe.

In the part of the paper by Mr Whitehead and Mr Snell, it is stated that service tests should be carried out on vehicles which have been re-bored or re-sleeved. I think this may introduce an artificial element into the field tests, unless the test embraces the whole of the life of the bore. Most lubricating oil troubles are experienced when the engine is worn, and if field tests are carried out with engines in relatively good condition, a misleading answer may be obtained.

I would like to ask the authors of the part of the paper on the radioactive-tracer technique for measurement of engine wear on what evidence do they assume that the whole of the iron in the consumed oil is lost from the system? Measurements taken on the balance of lead tetraethyl in an engine show that quite a significant amount of it finds its way into the lubricating oil. I should have thought that lubricating oil, burning on the walls of the cylinder much less efficiently than the fuel, would leave quite a lot of its ash to be returned to the sump. I would estimate that about 30 per cent of the ash would go down below to the crankcase oil, and that the rest would either remain as deposits in the combustion chamber or go out through the exhaust.

Concerning Mr Wilford's paper, I would like to ask why the two lubricating oil specifications are made so unnecessarily restrictive. Viscosity is tied up in a very elaborate knot, including a minimum viscosity at 140° F, as well as a maximum, and also a minimum at 210° F. The minimum at 140° F is surprising, since the author himself is one of the greatest advocates of low viscosity oils. I should have thought it sufficient to specify the SAE number, or possibly a narrower range of viscosity at 210° F only, together with the viscosity index.

Mr Perry states that metal segments are put into the vapour space above the oil, and mentions that their temperature is low. I wonder if he could give a more precise indication of what that temperature is; whether it is possible for the sludge to be wet, or whether it is dry.

K. R. Williams: An important point, which has not been discussed very fully in the papers, is the fact that when evaluating an H.D. engine lubricant and selecting it for a particular application, the oil, unlike the steel mentioned in the paper by Dr Kendall and Mr Richards, does change with use, and its performance deteriorates. New oil is supplied to the engine in two ways. First, in the charge of oil when the sump is filled, and secondly, in make-up oil. To achieve full benefits from additive oils, the lubricant chosen for a given engine must be such that a satisfactory level of performance is maintained throughout the desired oil-change period. If this criterion is not observed, then for a proportion of each oil-change period the engine will, in effect, be running on an oil of inferior performance, or even a straight oil. An engine subject to ring sticking or ring plugging on a straight oil may well suffer from the same troubles, if an additive oil is used whose performance does not remain at a sufficiently high level throughout the oil-drain period. When a short oil-drain period can be tolerated, then the initial performance level of the new oil need not be as great as with a long oil-drain period. It also follows that an engine with a relatively high oil consumption will not require an oil of such high initial performance as one which consumes but little oil. Therefore, for an

oil evaluation test to have practical significance, it must not only demonstrate that the oil is effective, but that it remains so for the required period.

In the case of the engines used by London Transport, I should not expect the performance of an oil which only just met U.S. Army Ordnance specification 2-104B to remain at its high level for the full duration of the 6000-mile oil change mentioned in some of Mr Wilford's past papers, but I should anticipate a marked improvement to arise from the use of certain Supplement I type oils. In our experience at Thornton, both improved engine cleanliness and reduced cylinder bore and piston-ring wear would result from the use of such an oil, and I should be most interested to learn, if Mr Wilford and his associates have any experience with Supplement I oils in buses. I was interested to note that Mr Towle and Mr Vaile find that, to achieve a given performance level, more additive is necessary in certain SAE 50 oil than in their SAE 30 counterparts when tested in the AV1 engine. We have not always found that in other tests, where little or no make-up oil is added. Presumably, the consumption of the SAE 30 oil was greater than that of the SAE 50 oil in the AV1 tests, which in turn implies that more new oil was added in the case of the lubricant of lower viscosity. I would be most interested to know if any correlation has been found between the oil consumption observed in the engine and the cleanliness rating in the Petter AV1 engine.

S. C. WHITEHEAD: Mr Wilford finds an 8 per cent increase in engine life when using detergent oils. It will be interesting to know what are the limiting factors in determining when an engine requires an overhaul, and in what proportion of cases the lubricating oil is involved as a possible contributing factor. A tendency to top ring sticking in engines on long-distance haulage would be expected with the prolonged high-temperature, full-load running involved, although oils meeting the MIL-0-2104 specification should completely eliminate ring sticking, provided that reasonable oil-change periods are used, say, up to 5000 miles. The use of 6000 to 10,000-mile oil-change periods, which is quite common among bus operators in this country, means that the oil will become heavily contaminated with combustion products which, after such a long period of use, it can no longer disperse. In such circumstances one might expect an oil of, say, Supplement I type to give improved performance. This is a point where the Caterpillar L.1 test procedure differs from that of bus operators in this country, and doubtless accounts for the absence of scraper-ring blockage in the L.1 test. I agree with the author that the marketing of two grades of oil, one for engines in long distance operation and the other for city buses, would be an inconvenience to oil companies and to operators, and should be avoided. If the principles of engine testing set out in the paper by Dr Kendall and Mr Richards are followed before marketing an oil, it will in fact be suitable for all types of service.

L. J. RICHARDS: My colleagues' and my own approach to the evaluation of engine lubricating oil performance has already been set out: we have contended that each and every property required of an oil in the field must be given separate attention. I think that one cannot fail to recognize that those at the " receiving end " of lubricants, as it were, also feel that

although the standard Caterpillar and Chevrolet tests are valuable, they do not evaluate all of the properties of lubricants which are of importance in service.

Mr Wilford makes this very point in his paper, and sees the necessity for additional tests to cover the lubrication problems in automotive engines—in particular, he refers to scraper-ring fouling and sticking. Mr Baddeley and his colleagues recognize that their needs are not adequately covered by existing specification tests, and, for example, identify corrosion prevention as an additional requirement. Mr Pearce contends, and one must support him, that oil performance is not closely defined by Caterpillar and Chevrolet tests—he states that several oils, all of MIL-0-2104 quality, may show up very differently in different engines. Mr Fogg and Mr Oliver make a case in their conclusions for a test procedure over and above existing specification tests. We ourselves have already made the point that field requirements, such as those discussed in the papers already mentioned, must be the foundation of any realistic evaluation of an engine lubricant.

It is therefore disappointing to read in so many other papers proposals for single test methods, which are justified very largely on the basis of their correlation with Caterpillar and Chevrolet tests. Little heed seems to have been given to oil characteristics not measured by these tests—for example, Mr Wilford's scraper-ring fouling.

The tests proposed in those papers are no doubt well justified in order to simplify and cheapen the development of oils which ultimately must pass the appropriate specifications, but on their own would appear quite inadequate for developing oils with excellent all-round performance.

The only test which appears to stand entirely on its own feet is that proposed by Mr Perry, but what will be the practical implication of results from this test? What does it measure, and how is it related to the many different problems connected with an oil in the field? It would be of considerable interest to hear Mr Perry's views on these points.

A. Towle: At least two contributors have suggested that ring sticking is not a service problem to-day, but before accepting this at its face value I believe that we should consider why ring sticking is not a problem. Many operators still carry out top engine overhauls at periods ranging from 25,000 to 60,000 miles, and some even re-ring at this lower mileage, the excuses given for these frequent overhauls varying from availability of staff to the necessity for re-facing valves at this period and the comparatively little additional cost of withdrawing pistons. In such short mileages ring sticking, of course, does not occur, but if, on the other hand, one were to attempt to carry out far greater mileages between each overhaul—as you can do on a high grade detergent oil—then ring sticking would be a problem when using untreated oils. The function of a detergent oil is therefore to extend the overhaul period, and in such circumstances, I suggest, there would be far greater correlation between the Caterpillar test and service performance.

The question which was raised by Mr Wilford of 2-104B-type detergent oils giving an 8 per cent increase in engine life also requires further consideration. An increase of 8 per cent may not sound much, but it must be remembered that the average engine life as calculated by the L.T.E. is

determined by when an engine is returned to the shop for any purpose whatsoever, be it broken fuel pipe or connecting-rod bolt. Hence, as far as those failures associated with lubrication are concerned, it is reasonable to suppose that the life of the engine has been at least doubled.

Mr Perry has suggested that his tests indicate a higher degree of sludging with high sulphur fuels than with low. This is contrary to our own and many other people's experience, which appears to show that, while high sulphur fuels produce considerably more lacquer than low, the degree of sludging is somewhat less. In connection with the BLOGRO oil test, we believe it highly dangerous to base such a procedure on the RG2 aircraft engine lubricating oil test, which failed to correlate with other aircraft engines, and was looked upon with suspicion by engine manufacturers, oil companies, and Air Ministry alike.

We agree with Mr Bell that a feeler test on a small single-cylinder petrol engine, giving correlation with the Chevrolet, is extremely desirable, but believe that, for full correlation on all base-oil additive combinations between the Petter W1 and the Chevrolet, it will be necessary for the former engine to use bearings of the same metallurgical structure as the Chevrolet.

R. J. S. Perry : With regard to the enquiry about the metal segments, the oil system consists of the oil tank with a glass cylinder above, to which it is connected by a short length of pipe, and the oil can be directed from the oil tank up into the cylinder to measure the rate of its circulation. Whilst the oil is flowing, which is for a short space of time every half hour only, the metal segments would be fairly hot—too hot for the hand to be placed upon them—but normally they are just warm. I should not think the temperature was more than 20° C. There is sometimes water present on these metal segments, but in most cases, if there is a deposit, it is oil sludge, which may contain water. We have only done the preliminary work, noting whether there is sludge present or not and whether the metal segments are etched or not.

We do not claim that the engine rates all the properties of the oil. For instance, everyone keeps laboratory engines inside a heated building. Few engines in service are started under those conditions, and yet the ease with which an oil could be pumped might be a very important point, and might produce temporarily, until the oil flow started, very high piston temperatures, due to the fact that the cooling effect of the oil had not been developed. Also, of course, the temporary lack of oil might cause inadequate lubrication. That is one of the factors that cannot be assessed, and therefore most of these attempts at wear can not give any correlation with service. But we do rate the oils with ring sticking, and also with attack on phosphor bronze. We do not employ abnormal running conditions —we are not trying to coke the oil. We are really running the engine at high performance, but not higher than that of many British and American touring cars. Most engines do not run at that condition continually, but for periods, and the longer these periods are, the more they approximate to the effect that we get. That is why, on the long-distance buses or haulage vehicles, the effect of this higher temperature is borne out.

Most people regard ring sticking as a complete locking of the ring in the

groove. I have found that it is not necessary to lock the ring in this way to obtain the effect of ring sticking. Wedge-section rings automatically spring out of the groove, because immediately there is the slightest bit of movement they are free, whereas parallel-sided rings will have to be moved completely clear of the groove before they are free of the deposit that is holding them. Rings are given a side clearance to enable them to line up with the cylinder bore when the piston tilts. If they lose their side clearance, they are not able to function properly. A test for ring sticking on wedge-section rings gave precisely the same ring-sticking time as with the parallel-sided rings—in other words, it was the loss of side clearance, rather than the sticking of the ring in the groove, that was important.

An SAE 5 oil, with its higher circulation rate, gives a greater flow of oil on to the piston, and therefore a greater cooling effect, and the temperature of the piston is reduced. Correspondingly, the oil temperature in the sump increases. With the SAE 30 oil it is necessary to lag the pipes of the oil system to maintain the oil temperature at 100° C. With the SAE 5 oil it is necessary to use the oil cooler to extract the heat.

R. COURTEL : At the French Institute of Petroleum we have used for some years the Petter AV1 testing method. In certain cases it has been noticed that the chemical composition of the gas oil used has considerably affected both the running of the engine and the cleanliness of the piston after test, although all the physical properties of the gas oils were apparently very similar.

Two gas oils complying with the MIL-0-2104 specification were used, one having a cetane index of approximately the upper limit (45), the other having a cetane index of approximately the lower limit (40), and both being composed of straight run gas oils from various sources. In the case of the gas oil with the lower cetane index, there was very frequent injector fouling (every 6 hours), and also considerable formation on the piston skirt. The injector fouling was found to be caused by whitish deposits containing, amongst other compounds, those of zinc and calcium.

Chemical analysis revealed that only traces of these elements were present in the fuel, and it was necessary only to add to the latter 20 per cent of a paraffinic gas oil for the injector trouble to disappear, as well as the deposit which had caused it, without raising the cetane index above 45. Under these conditions, there was no appreciable change in the proportion of varnishes deposited on the piston skirt.

I have mentioned these two phenomena, which seem difficult to interpret, in order to hear the comments of others who may have come across similar cases.

F. WEATHERILL : Six and a half years ago the IP informed members about a Panel which was to consider engine testing, and I had hoped we should to-day hear what had transpired. However, that Panel has not yet presented its report, and there are still remarkably few signs of progress. The only thing this afternoon, which is in any way new to most of us, is the contribution which referred to the BLOGRO Engine. In so far as subsequent speakers have commended Mr Perry's paper I am delighted.

Dr Clayton referred to the formation of a committee in which he conceives the IP, users of transport, and the manufacturers of engines co-operating. I would like to support this idea, and hope that such a committee is created and that it will give proper assessment of the value of those methods which either existed six and a half years ago, or that have been modified or created since. The continued acceptance of engine tests which, due to high capital costs and limited operation, make for exclusiveness is most undesirable. The Institute should stimulate and encourage efforts to establish a less costly method.

R. W. Long : Following the trend of the last speaker, I think that, on the engine side, we have probably reached a degree of standardization in diesel combustion chambers which should greatly simplify the task of the lubricant specialist.

In the early days of high-speed diesel development there existed a multiplicity of combustion-chamber designs, and there were frequent cases of fuel spray impinging on the walls. Ring sticking was naturally very prevalent. Nowadays, we find that in Britain the tendency is to standardize on the toroidal combustion chamber. With this arrangement, the fuel spray is kept well away from the cylinder walls, and the air " squish " is inward at the time of fuel injection. Contamination of the oil from raw and partially burned fuel should thus be considerably reduced.

Therefore, there should be less demand for additives in oil than formerly. I feel that the use of these additives should be reduced because, with petrol engines, which form the bulk of the engines in military vehicles, it would be very difficult to make a case for additive oils. They do no harm, perhaps, but I doubt very much whether they do any good. The present position is that we tolerate them in the interests of standardization.

On the subject of thin oils, it would appear, from the illustrations, that the use of a thinner oil will inhibit piston fouling due to the higher circulation rate. By all means, therefore, let us use thin oils and reduce the additive content.

J. E. Pratt : Many years ago the first diesel engine was installed in one of the Royal Naval Dockyards using kerosine as fuel, and no trouble was experienced with its lubrication by general purpose engine oil. To-day, in spite of developments, we always seem to be having trouble. The lubricating oil is generally blamed for this, but I think the last speaker was more correct : it is a question of combustion.

The higher sulphur content of present-day fuels has undoubtedly brought difficulties, but only the lubricating oil manufacturers are expected to overcome these by improving their products. It may well be that some of the chemical additives used to do this contribute to faulty running, and increase wear and tear above normal, although longer periods of running between oil changes may take place. Are not corrosion and wear, of which there are complaints, mainly due to foreign matter taken in with the air? Methods of efficiently filtering the air may help towards cleaner and better running.

High-grade straight mineral oil successfully lubricated all types of diesel engines for many years. The idea that oil deteriorates in service is not

correct; when the *Mauretania* was taken out of service, a large percentage of the original fill-up was still in the tanks. High-grade oil is indestructible with proper care.

Test engines in laboratories, by allowing performance of fuels to be studied under ideal conditions, give valuable data to designers. It is doubtful if the same can be said of lubricating oil evaluation, since the performance of the oil depends upon the actual working conditions of the engine. No two engines are exactly alike, and an engine's performance in one place may not necessarily be the same elsewhere. The fuel performance is under mechanical control; the lubricating oil performance is not, as it depends upon many variable factors.

The tendency of users, and sometimes engine manufacturers, to insist that the lubricating oil must conform to some special physical condition, such as a definite specification, or some group specification, such as SAE numbers or BSI grouping, also operates against test-engine results. The latitude of these various groups is too great for selectivity. On the other hand, the definite specification demanded by some engine manufacturers is far too selective. The correct selection of the oil for an engine must allow for a certain latitude of range to meet local working conditions.

It is doubtful whether test-engine results will ever give a complete solution to the problem of estimating or evaluating lubricating qualities of oils. The variation of working conditions are too great to be simulated in a laboratory.

J. ROMNEY: I was particularly interested in the paper on the examination of engine deposits. Most oil chemists are, from time to time, faced with the problem of examining deposits and drawing conclusions from them. A deposit is analysed and studied in various ways, and, as a result, engine tests are devised to try to produce similar deposits. That is logical enough, but the customer has to be warned that he will get his answer in three or four years.

This is not intended to be a criticism. The authors of the paper are not thinking in terms of a single deposit, but are almost certainly considering the regular incidence of a particular type of deposit in a particular type of engine. Presumably, their object is to produce, in an engine test, conditions which will give rise to a similar deposit with the same oil, so that they can then experiment with modifications to the oil, designed to prevent the deposit forming under the same engine conditions—a very reasonable procedure, but still a very lengthy one.

The IP Committee which has spent so much time on engine tests and, according to one speaker, produced nothing, might devote itself to what amounts to the opposite procedure. They would run engine tests under different conditions to produce different deposits, and issue tables of analyses of these deposits, with details of the conditions or faults which give rise to them, then, when a chemist had a deposit to deal with, he would analyse it, then refer to the tables, and report much more definitely to the customer than as in the past. One of the chemist's biggest routine problems is to try to come to a decision as to what has happened, on the basis of the examination of a single engine deposit.

I should like to raise a small point with the authors of the paper dealing with the examination of used oils. Most of their work has, I believe, been

done on diesel lubricating oils, and they refer to one necessary test as being that for fuel dilution. It is well known that the IP test for diesel fuel diluent is useless, and it will probably be abandoned. It would be very helpful if the authors would let us know what method, other than the IP method, they have been using.

A. WATSON : I was not a member of the IP six and a half years ago, but I believe that the new BSI specification does include at least some views of the IP, so I assume the IP has done some work on it.

With reference to both Mr Towle's paper and the other paper on the Petter engines, both petrol and diesel, it seemed to me that if we can not get exact correlation down to the border-line oils, at least we have got such good correlation with good oils, that some alternative acceptance might be allowed, at least for the Caterpillar test. It might be possible to rate an oil which safely passes the Petter test as being the equivalent of one that passes the Caterpillar test.

None of the speakers has said that we ought actually to do away with the American test engines. I think we are very near correlation with these engines, and therefore we ought to arrange a substitution.

I would like to ask Mr Perry a question. It was not clear to me that any of the tests which he is doing get his oil manufacturers anywhere nearer to selling oil. I should have liked to know whether he had correlation with Caterpillar engines, or any of the other engines or specifications on which oil is sold. I wonder whether Mr Perry would enumerate any of the tests he has done which can be correlated with those which enable oil to be sold to any specification ?

R. J. S. PERRY : We have not tried to make any correlation with the Caterpillar test, but have used a British test. We have worked on the basis of a condition which is obtained in engines, when they are operating at high power, such as that envisaged by the phrase " heavy duty oils." We seek oils that will pass that condition.

The Caterpillar test is forced on the economy of the U.K., which will have to pay the very heavy price of expensive tests. Test facilities are limited to a very few companies, which restrict the suppliers of these oils. I do not agree that the American test is in any way the best. Engine testing of oils was undertaken in this country before any of the Caterpillar tests were envisaged, and I think we should continue to use our own resources.

J. ATKINSON : I would like to reply to Mr Withers about the Fowler engine tests. He does not like the high piston-temperature that obtains in the test because he feels it is unrealistic. If one accepts the philosophy set out in the paper by Dr Kendall and Mr Richards, criticism of a test itself may be made, provided that the property that it evaluates is an essential one; with the Fowler engine test we merely aim to evaluate ring sticking. One might perhaps agree that the temperature is high; it is intentionally so, and was designed simply to emphasize the oil property requiring measurement. There may be others who could say better than I whether the piston temperature achieved in the Fowler test is exceptionally high or not.

Mr Wilford has been able to identify oil ring-plugging as being one performance factor that should receive more attention, and on reading the paper by Mr Fogg and Mr Oliver it would seem that, whilst there is some agreement with Mr Wilford on this point, there are also data contained in their paper that, taken separately, might suggest some disagreement. Nevertheless, Mr Fogg and Mr Oliver were able to identify types of operation of public service vehicles and the importance of these, and came to certain conclusions as to the important oil-performance factors in each type of operation. Now, in order to satisfy each of these properties, one would have to make several engine tests, or, in effect, a test in a single engine which would do all those things. I personally do not believe that the latter is possible.

In the paper by Mr Baddeley *et al* reference is made to performance tests, and it is stated that " a generally accepted performance test, by the time it reaches some degree of international standardization is no longer representative of general user practice." Unless one can properly identify the properties that the oil needs to exhibit, not only will a single test in a given engine be no longer representative of general user practice, but it will not even start being generally representative of practice, and I would like to ask Mr Baddeley what he means by " general user practice." It would seem that, whilst many speakers prefer a British engine, the service referred to by Mr Baddeley *et al* is likely to include a wide variety of makes and types of engine in special military equipment and commercial vehicles, and this fact might cause him to have different views regarding the merits of particular engines.

J. L. Heaton : Having listened to so many contributions concerning deposit formation and piston-ring sticking, I feel I should mention wear again. Although ring sticking may be a spectacular type of failure, I think that the typical fleet operator, at least in regards to diesel engines, is concerned just as much about engine wear as he is about ring sticking. In saying this, I am continuing the tradition of telling the operator what the oil business thinks his problem is, and I would be most grateful if any operator would comment on the seriousness of his wear problem.

I suggest that this wear problem is becoming much more apparent these days, because to some extent we understand and can overcome the problems of piston-ring sticking and deposit formation, in spite of the rather gloomy view taken by Mr Weatherill and other contributors.

I will say a word in defence of the Caterpillar engine, which has been attacked once more on technical and other grounds. I do not think it is fair to leave the impression that the Caterpillar engine was forced on the U.K. due to pressure from abroad. The Caterpillar engine was adopted by the oil industry in the U.K. as a testing method, because it was cheaper to use an existing, well-established test, such as the Caterpillar, than to begin developing a new alternative test.

C. G. Tresidder : I have one comment concerning the status of the RG2 test for evaluating lubricating oils for certain piston-type aircraft engines. Those with some knowledge of the post-war position regarding engines under flight conditions often wonder why the RG2 test was ever

instituted. It is probably fair to say that no adequate correlation has been shown to exist between this test and actual service results.

J. H. WELLS: I should like to express some thoughts on correlation. I feel that we must consider " where do we go from here." We have had views on a wide diversity of engines, and techniques with those engines. But unfortunately, apart from the Ministry of Supply, the War Office representatives, and Dr Wilford we have heard little from operators.

But correlation in the laboratories with operating conditions in service is surely the be-all and end-all of " engine testing." I was very struck by the candour of Mr Fogg of MIRA, who said he had failed to correlate with service experience. It seems that many advocates of the L.1 test have not failed because they have not even tried. I would suggest that what is wanted to get real advantage from this wealth of information is to collate an equal body of information from operators, so that we can answer the question " What conditions do we want to simulate? "

Service conditions fall into two groups of variables, the first being different operating conditions between engines of the same make, and the second being differences in design of engines in similar service. It is surely an impossibility for a single engine-test to cover two groups of variables, each having a whole series of variables within the group. Mr Fogg recognized by reference two operators, and three different classes of service. Might I suggest that in aiming for a universally acceptable test-engine, that we should consider the possibility of running the selected test-engine under three sets of conditions, and rating oils in three different categories, according to the different services for which they may be required. The API, of course, recognize five different service categories, but three would probably suffice if we are mainly considering diesel conditions.

We all aim at reducing the period of the test, and we mostly seem agreed that this cannot be done by unduly elevating temperatures. There are possibilities for some accelerating of the test by reducing the quantity of oil in circulation, without resort to elevated temperatures, by keeping that reduced quantity under control with a cooler.

To summarize, I would urge that what is most needed is the collection of data from operators, as to their problems, operating conditions, and certain design characteristics of their engines. That data could be collated either by the Automobile Division of the Institution of Mechanical Engineers, or by the API, and, by answering the outstanding question " What conditions do we want to simulate? " would guide the design of a standard test-engine and the several conditions under which it should be run.

E. R. PALMER: I think we have all taken rather a parochial view on what we are going to test in these oils; I have not heard any mention of conditions outside the U.K. Our engineering industry now is based on important exports to Europe and elsewhere, and we have not touched on the conditions of tests required in, say, winter-operating conditions in Scandinavia, or on cold-testing conditions, nor have we referred to the matter of lubricating service, using fuels other than ideal types. A lot of work is being done on the use of heavy fuels, particularly in marine engines, but we have heard nothing about that aspect.

There is one point I would like to make on Mr Towle's paper. There seems to be an underlying assumption, possibly fallacious, that sulphur content is the by-all and end-all of a fuel. I am sure that is too simplified; sulphur content is not the only criterion. Let us take the analogy of the use of different scavengers in gasoline to get rid of lead. It is well known that ethylene dibromide and other bromine compounds, such as acetylene tetrabromide, which only differ slightly in boiling range, do give totally different results in lead scavenging. That might be expected, but I think that it is equally likely that varying sulphur compounds would be expected to give equally varying results in engine tests. Simply to plot, as Mr Towle has done, wear and other factors against sulphur, where only three fuels are being considered, does, I think, assume too much. I think this sometimes misleads our users. One has this sort of query put to one: "The sulphur content of the fuel is so much, therefore what type of oil does that require?" I do not think it is as simple as that.

Dr Clayton has suggested that we should get back to laboratory tests, but I do not think that is ever likely to be possible. The analogy drawn between testing an oil and testing a steel is rather false. A steel does not change much in use, whereas an oil is a tremendously complex mixture of hydrocarbons of varying stability, and the type of test applied to it would be entirely different to that for a steel. On these engine tests, we start with a very good basic data, with the L.1 and the L.4 tests (the latter is open to criticism). But they are tests with certain field correlation, and I think we are right to take them as a pattern, and to try to get something cheaper and simpler which will correlate with those tests. We should do well if we could say at the end of our work: "There is a correlation with the Caterpillar or the Chevrolet." Sub-standards of reference are quite common in all fields of work. Besides, the L.1 and L.4 tests do not just apply in the U.K., they have world-wide acceptance, and I think we should be rather parochial to reject them. That does not necessarily mean that a test which correlates with these is the only one we want. There is a lot of work being done in the States on service under cold operating conditions, *e.g.*, the FL2 and similar tests. I do not know of any comparable work that is being done in the U.K. on passenger-car operation, particularly for export use. We have two tests—the AV1 and the Petter W1—that are nearly ready for going into practical trial use, but we want some other test for cold operations; together all these tests would give us a fairly complete picture.

R. Smith: Mr Roegiers stated that additive oils increase wear. Our experience is typified by the data which are given in the paper by Mr Williams and myself on the application of statistical techniques to engine testing. I think that the results given there show that suitable additive oils do not increase wear, but that they reduce wear significantly.

In Fig 7 of Mr Bell's paper, the author gives a regression line, but does not state whether it is a regression of Petter results on Caterpillar results, or vice versa. The limits about such regressions are usually defined about the centroid of the two regression lines, and I would therefore enquire whether the limits given are those about the centroid? If so, the limits at the extremities will be greater than indicated.

The term " correlation " is very often used without mention of degree, and this has been done regularly in the discussion. It is to be deplored, I feel, because it is only when the degree of correlation is defined that it has useful meaning, and only then if significant correlation is obtained between, for example, laboratory test and field, so that the reliability of prediction can be assessed.

I would enquire of Mr Wilford whether greater wear occurring under conditions of stop–go operations alters the order of ring sticking from compression ring to scraper ring, as obtained under long journey operation. It seems possible that greater wear of compression rings and grooves, obtained under stop–go conditions of operation, might alter the ring side-clearances sufficiently to change the order in which ring sticking occurs.

We have been asked " What has happened to the test engines developed by the oil companies ? " The Shell-Ricardo engine has been, and is now being, used extensively at Thornton Research Centre for the assessment of various oil characteristics, such as wear, cleanliness, etc. In our paper, Mr Williams and I have given some data on correlation between tests A and B (Table III). These data are obtained from a programme carried out to investigate the degree of correlation between the Shell-Ricardo engine test and the Caterpillar L.1 test. It will be observed that, despite the good correlation achieved, the accuracy of prediction of Caterpillar test results from Shell-Ricardo test results, although possibly good enough for screening purposes, is not satisfactory. It cannot, however, be stated yet which test gives the better indication of the field performance of a particular oil.

Dr R. V. Hughes (written contribution) : The fundamental reason for introducing a lubricant at all in an engine is to reduce wear ; ring sticking, carbon deposit, etc, are incidental, though serious, problems resulting from its use. The number of different engines with varying times to produce serious failure of the piston assembly clearly indicates that piston deposits are a function of engine design (and I include in that the specific conditions for which it is designed), and it is reasonable to assume that, with a given oil, an engine could be designed such that wear would be the limiting factor in its life. It is doubtful whether, with the present state of knowledge, such a design could meet the requirements of specific output, but the principle remains, and I feel that, in the papers presented, there has not been sufficient emphasis on the lubricating qualities of oils.

My experience has been with engines of the stationary, marine, and rail traction types in bore sizes of 6 to 15 inches diameter. The flexibility of performance necessary in road haulage engines is not a requirement in these heavier diesels, load and speed conditions being in general much steadier. In road transport engines load and speed vary widely and independently, so that extreme conditions, low piston-temperature and high speed, resulting in a high rate of oil consumption, and high piston temperature with low speed, resulting in low oil consumption, frequently occur.

On the larger engines, therefore, it is not so difficult to simulate in the laboratory the conditions likely to arise in service, and normal engine tests give a fair proof of any lubricating oil. Generally, the oils tested are those presented for trial from time to time by the oil producer. The tests are

limited in scope, mainly because they are limited in time, and it is obvious that for wear comparison at least more sensitive techniques are required.

This complex problem might be simplified if divided into two lines of development, to be carried out respectively by the engine manufacturer and the oil producer. The engine manufacturer should design his engine to obtain the best performance with the materials available, and should, by careful design, minimize adverse conditions, by limiting output if necessary. The oil producer should progressively improve those aspects of his products which are known to be deficient. The final proof of engine and oil can only come from testing the two together.

The engine tests described in these papers would thus be regarded as the devices used by the oil producer to test his oil for specific properties. This is essentially the idea put forward in the paper of Dr Kendall and Mr Richards. Carrying their analogy a little farther, I would say that just as the steel developed by the metallurgist is proved finally as an integral part of the machine, so must an oil be treated as a component in the development of an engine.

It is notable that in the papers presented, only in one case have oils been rated according to their lubricating properties.

The engine designer attempts to achieve hydrodynamic lubrication, and under such conditions at ordinary temperatures, the only oil quality having effect would be viscosity. There are limitations due to the mechanical form which prevent this ideal state. Thus, so long as a piston reciprocates in a cylinder, boundary lubrication will develop at the extremities of ring travel, and so long as an engine is required to stop and start up again, boundary conditions will occur in the bearings. Due to the work of Bowden and Tabor, Barwell, and others, there is a growing realization of the importance of the surface layer under boundary conditions, and of the part played by the lubricant in its formation. Therefore, there should be more information on the behaviour of these lubricating oils and particularly the various additives under boundary conditions at the temperatures, pressures, etc, reached in engine operation.

Yet another aspect of the lubricating oil problem not considered is oil consumption. It is fairly well established that high duty or additive oils generally result in increased rates of oil consumption in a given engine. This cannot be entirely due to the cleanliness of the piston assembly, since it has been shown that the consumption rate is higher than with a straight oil, even with clean assemblies. It is reasonable for the engine manufacturer to suspect that the additives are responsible, but so long as these are labelled A, B, C, etc, by the oil producer, and no other information is forthcoming, there can be no logical programme of development.

Summing up, it seems to me that engine testing is becoming a way of avoiding the fundamental problems. I am not convinced that results from an engine test, in which rapid blocking of the scraper ring is produced artifically by the use of a high-sulphur fuel, give any better indication of the behaviour of an oil than would a completely artificial rig. The engine tests are, after all, comparative, and it is difficult to see how they can ever be otherwise.

I would like to make a plea for more detailed research into the behaviour of lubricating oils and for the transmission of real information to the engine

manufacturer. Technical co-operation between the oil producer and the engine manufacturer is imperative if the intensive development towards higher powers and speeds is to proceed without much wasted effort.

R. STANSFIELD (written contribution): Mr Pearce comments that top ring groove wear is not influenced by oil type. This probably refers to engines running on Class B fuel—a very variable factor which has wisely been deleted from standardized oil-testing technique. Although H.D. oils necessarily differ between themselves in details of behaviour for a given general specification, it is well known that they do reduce top ring and groove wear when the engines run on distillate fuels; they do many other things also, and Mr Pearce rightly refers to these as well as to the limitations imposed by change from a distillate fuel to a cheaper grade.

Mr Wilford wonders whether all oils meeting MIL-0-2104 specification would be equally satisfactory in all respects in service. The general answer must be " No "—an answer which will always be true as long as there are different makes of engine, differences between running conditions, different kinds of fuel, and different base stocks and additives in lubricants.

Even laboratory engine acceptances depend on the oils passing a number of quite distinct minimum standards of quality, and the margin above each minimum varies from one quality factor to another for a given oil. Thus one oil may just pass for ring groove carbon, having an ample margin for lacquer, while another may be on the border line for lacquer, but show relatively little groove carbon. It is tempting to argue from this that the second oil will be the better in an engine prone to top ring sticking, and even to conclude that the standard of acceptance is wrongly set because it rates both oils as of MIL-0-2104 quality. This false logic ignores the reasons given above for the answer " No." But Mr Wilford sees the problem in better perspective; he makes exhaustive service tests, and if an oil shows itself to be economically good he adopts it, whatever the laboratory test used in its specification. He suggests, however, that a cool running test might be more appropriate for oils for many vehicle engines, while agreeing that long-distance work gives top ring sticking. If I understand him correctly, he suggests two tests and two different oil classifications, one of which is not far from MIL-0-2104 for long-distance, heavy-duty vehicles. The other for bus duty is, at present, a theoretical one based on the assumption that the MIL-0-2104 tests fail to grade oils for low-temperature duty *because* they are run at a high temperature. But until results of suitably controlled low-temperature and, necessarily, very long tests are available, the need for them is only an assumed one. There is, indeed, ample evidence to show that MIL-0-2104 oils are definitely better for resisting sludging and scraper-ring choking than straight oils at low engine-temperatures, and, as experience with H.D. oils grows, one may doubt whether a low temperature test will lead to any appreciable alteration in the average quality of these lubricants. It might result in a slight improvement for easy duty at the expense of one or other of the heavy duty factors, while still retaining these within specification limits, but it is hard to believe that the service gain already obtained from H.D. oils by Mr Wilford can be retained if there is any reduction of additive content, or that any reasonable cool

test will lead to a sufficient alteration in quality to justify either two test methods or two different oil types.

The paper by Mr Baddeley and others contains demands which, I submit, are unreasonable for the users of oils to make at present. I am surprised to see the suggestion that the heat-transfer properties of a lubricant might be modified to such an extent that a major improvement in engine performance would result. With reference to engine tests, surely if the oil suppliers consider that these should not be unduly short, it is not for the users to shorten them further. No supplier makes a long test without good reason. It is unreasonable to ask for a combination of a cycling test, including cool running to give corrosion, a hot run for ring sticking, a blow-by test, one for film strength, and an engine performance test all in one short run !

Commenting on the third paragraph of the suggestions in this paper, I can not agree with the authors concerning performance testing. The experienced engineer does not allege that fatigue tests are a confession of failure on the part of the metallurgist, or that type tests imply failure of the engine designer and builder; the performance testing of lubricants is, in effect, fatigue testing or type testing, and deserves appreciation as such.

Performance testing introduces two factors for which no theory of lubrication or knowledge of the physical and chemical properties of lubricants can provide. It supplies the products of combustion and partial combustion with which the lubricant has to deal, and it also allows for the effects of details of engine design for which no one could estimate on theoretical grounds. The most satisfactory selection of lubricating oils is made by those users who are constantly carrying out their own service tests, and the best advice comes from those who make the most intelligent use of test results from the widest range of engines and the largest selection of oils, both in the laboratory and the field.

Replies to Discussion

L. J. Richards and his co-authors jointly wrote as follows in reply to the points raised : Mr Withers is disturbed at our suggestion that laboratory test engines should not be used to simulate conditions in the field. One is concerned, of course, with simulating or reproducing the field *problem* in the laboratory engine, but to do this it is quite unnecessary to effect exact reproduction of the *operating conditions* of the engine in the field which is suffering with the problem. It is necessary only to identify the essential features of the conditions leading to the problem (the engine in the field may spend very little of its life actually running under these conditions) and impose these on the laboratory engine.

Regarding Mr Withers' second point, it is accepted that there exist in the field a variety of engines and types of service, each of which must be satisfied. One must pick out the worst performance feature of each engine and type of service, and ensure that the lubricating oil to be applied will meet requirements on each count. It is agreed, for instance, that piston ring sticking is very much affected by piston temperature, but for an oil to be suitable for given applications it must measure up to the highest piston

temperature likely to be met in the field. The latter is obtained through field studies.

In connexion with field studies, Mr Withers mentioned that the use of re-conditioned engines in field tests might give misleading results, and that the tests should be run for the whole life of the engine. It is true that over very short periods of test operation engines which are virtually new might give results of limited value, but, even so, relative rates of deterioration in engines can be assessed. We would agree that it is desirable to continue tests over the full overhaul life of each engine, but there are sometimes practical considerations which limit this practice. First, such tests might extend up to three to four years in duration, and, secondly, as Mr Towle has pointed out, many operators prefer to strip down their engines at pre-determined mileages, irrespective of their condition.

In the paper dealing with the radioactive tracer method, it was assumed that the oil consumed carried with it a quantity of active material appropriate to the concentration of this material in the crankcase oil. This assumption was questioned by Mr Withers, who suggested that a considerable proportion of this iron was returned to the crankcase. However, most of the oil is lost from the combustion chamber region, and is richer in active wear products than is the crankcase oil. This will oppose the effect suggested by Mr Withers.

An experiment with some bearing on this question has been run, in which the engine was fitted with an *in*active ring immediately after a run with an active ring. The oil is not changed, and no make-up is added. If Mr Withers' suggestion is correct, the concentration of active material should increase as oil is consumed. No such increase was observed.

Referring to a question from Mr Romney, the IP method for measuring diesel diluents is admittedly very inaccurate. However, the fuel dilution is measured merely to check that there has been no gross leakage of fuel into the circulating oil—a condition which would seriously affect the validity of a field test result. It is thus sufficient to know whether dilution is greater than, say, 5 per cent, and not necessary to know whether it is, say, 2·4 or 2·6 per cent. The IP method would thus appear to be adequate, except, perhaps, in the case of SAE 10 or 5W oils.

Mr Palmer, in commenting on various approaches to lubricating oil testing, has said that the analogy between testing an oil and testing a steel is rather false, adding that steel does not change very much in use, whereas oil, being a complex material, is very different. We would suggest that Mr Palmer is taking too narrow a view of the analogy drawn. We agree with him that the actual types of test which have to be applied to the two materials—oil and steel—differ considerably, but the basic approach to the evaluation of each can be, and should be, identical. That is to say, we must set out to measure, and if necessary develop, the specific properties which are pertinent to the satisfactory achievement of our aims, whether to build a bridge or to lubricate an engine. Metallurgists tell us that even a steel is not so simple, and fatigue testing is a common example of taking into account the changes in properties which occur during the useful life of a material.

A. T. Wilford: Dr Clayton rightly says that it would be illogical to purchase H.D. oils at increased cost if overhaul is determined by factors

other than lubricating oil deterioration. No operator would be prepared to pay anything for engine cleanliness *per se*.

Mr Withers asks why London Transport's specifications for engine lubricating oils are so restrictive in respect of viscosity. In the first place, the specifications are based upon oils which have actually been tested in service and have proved satisfactory. Secondly, in order to ensure obtaining an oil of SAE 20 viscosity, which would be significantly thinner than a SAE 30 oil, it is essential to specify close limits for viscosity. To call for an oil within the SAE 20 viscosity range, without further restrictions, would allow the supplier a very wide latitude. If he chose to deliver oil of the maximum permitted viscosity, there might well be an increase in fuel consumption of as much as 3 per cent compared with that obtained if the lubricating oil were at the bottom of the SAE 20 range. A specification in which the viscosity limits are strictly controlled is therefore entirely in accordance with my views on the advantages of low-viscosity oils. London Transport is at the present time carrying out very large-scale tests with oil of SAE 10W viscosity. If and when this grade of oil is adopted throughout the fleet, it will be necessary to issue a specification—again based upon service experience—indicating the particular sort of SAE 10 oil required.

Both Mr Williams and Mr Whitehead have referred to the question of oil-change periods, and have suggested that a 6000-mile period is too long. But during this period the detergent oils in use do not become completely depleted of additive; this, in fact, does not occur at 7500 miles, which is our present oil-change period. During the war years, oil changes were on a 12,000-mile basis; detergent type oils were in use on an experimental scale, and were found to contain a small amount of additive even after this comparatively long mileage.

In reply to Mr Whitehead's question about the limiting factors which determine when an engine requires overhauling, it is the piston assembly which gives most trouble. Engines are ultimately removed because of noise, or heavy oil consumption accompanied by "fuming" arising from excessive engine blow-by. The 8 per cent increase in engine life obtained by London Transport, when changing from plain to detergent-type oil, represented an overall increase, engine life being defined as the mean life of all engines removed for overhaul, whatever the cause.

Mr Pratt says that the definite specification demanded by some engine manufacturers is far too selective. If the specification is based upon exhaustive service tests and is correctly drafted, I am inclined to the side of the engine manufacturers.

With regard to a point raised by Mr Heaton, it is ring sticking or ring plugging, rather than wear of components, which causes us to change engines.

In reply to Mr Smith, the alteration in order of ring sticking is more likely to be associated with ring belt temperatures than with the greater wear associated with stop–go operation.

To comment on Mr Stanfield's contributions, I am not really advocating two different tests and two different oil classifications, if one test and one oil will do. The engine test should be capable of rating oils in the same order as they would be rated by engines in service, having regard to the fact that service conditions may vary over a wide range.

D. L. BADDELEY: The U.S. Army tests of the Caterpillar of the L.1 and L.4 type were introduced by the Services in this country, and not by oil companies. The first actual specifications were Service specifications, and they justified the acceptance of the American tests, without any consideration of the possibility of devoting time and money to the development of new British tests.

The meaning of "general user practice" can only be answered in a rather indirect way. A performance test in the process of laboratory standardization to obtain reproducibility, becomes less and less representative even of those conditions it was designed to reproduce. One must regard these tests purely as complicated methods of measuring certain properties. The Caterpillar L.1 test itself is a good example, since it has developed as the result of a Service complaint in the U.S.A., that engines of a particular type were suffering from excessive ring sticking. It has been implied that the Caterpillar had no background of Service requirements—that is not true, but the time taken for the test to become widely acceptable and widely used has outstripped occurrence of the trouble.

In reply to Mr Stansfield, we only suggested that additives might well change the heat transfer properties of the lubricant. If so, this should be revealed. Regarding our short term suggestions, there is an implication that we have asked for too much. Long hours of steady running do not normally show up the weaknesses of any material under test. There is nothing to prevent bench contacts of lubricants with combustion products with much less trouble than in an engine, while the argument that engine design characteristics are tested is valid only if all engines have the same design or an infinite number of tests are carried out.

The long-term policy is the one of basic research. The short-term policy is to modify tests so that they become more realistic, and while we have asked for the removal of performance testing, we will be satisfied with the progressive decrease in complexity and time of testing. Engines may be used, but if one is used to evaluate certain requirements, the test procedure must be short, simple, and repeatable, and there is no particular reason why it should correlate with the L.1 or the L.4.

D. M. PEARCE: My Company does not accept the standard tests without question, because it carries out its own, although the standard tests are a useful guide. No standard test will do away with the need for the individual engine builder to test his own engine on a specific oil, but it should be a useful guide when individual tests are not possible.

As to the question of replacing the American tests with British ones, patriotic and technical issues tend to get confused; the important thing is to evolve a better test.

G. R. OLIVER: Mr Towle said that ring sticking was not a problem, because of low mileages between overhauls. The transport industry would regard 25,000 miles as an extremely low mileage between top overhauls, and it actually operates on a mileage of about three times that figure. It has been implied that the Caterpillar test is applicable to long-distance haulage in this country. We do not accept this as being necessarily true, because our experience among operators is that compression ring

sticking is not a problem in this field. With more prolonged full-throttle running, there is certainly a tendency away from plugged scraper rings towards stuck compression rings. We would like to associate ourselves with those people who make a plea for correlation with service, but it is very necessary to strive to obtain complete data upon which to base conclusions.

J. C. CREE: In defence of the IP Panel formed six and a half years ago, it has been pointed out that the IP Sunbury engine, a lubricating oil test-engine designed with the co-operation of this Panel, has already been fully reported, and is being used for testing lubricating oils under a variety of operating conditions. Similarly, details of the Shell-Ricardo engine have been published, and several of these engines are now in operation. The paper I presented concerning the Caterpillar L.1 and Chevrolet L.4 tests can be considered as a report of part of the work originated by the IP Panel, and only a relatively small section of its activities have been covered.

Mr Wilford has stated that the conditions of the Caterpillar L.1 test are such that if ring sticking occurs at all, it is the top compression ring which is first to be affected, the trouble being progressively less with the lower rings. Although relatively few tests have been made on oils likely to give ring sticking by the Caterpillar L.1 procedure, as normally only oils which have passed a screening test are examined, for reasons of cost and engine availability, results on poor performance oils indicate that ring sticking invariably occurs in the reverse order to that suggested by Mr Wilford. For example, two such tests gave pinched third compression rings with all other rings free, and in another test the third compression ring was cold stuck, the second compression ring pinched, with the other two rings free.

I believe that the order in which piston rings are affected by deposits is unimportant, as it appears that this is related to the temperature at which the oil breaks down to produce the tacky (lacquer) deposits which cause ring sticking. It is possible that, when operating two engines on the same oil, one may stick rings in the manner suggested by Mr Wilford, while in the other, ring sticking may occur in the reverse order. This could be due to differences in design or operating conditions causing lacquer formation in different parts of the ring belt.

We have noted from the examination of Caterpillar pistons where ring sticking did not occur that, although lacquer was deposited in the ring belt, the deposits have often been heavier in the scraper and third compression ring grooves than in the second and top ring grooves. The explanation of this may be that the most unstable components of an oil are removed shortly after it reaches the elevated temperatures which exist in the ring belt zone and comes into contact with the blow-by gases. The oil which passes by the lower piston ring is then more stable, from the point of view of reacting with blow-by gases, and does not, therefore, produce lacquer deposits to the same extent in the second ring groove. Admittedly, the deposits in the top ring groove are invariably heavier than in any of the other grooves, but these normally consist of hard, dry carbon, and not the tacky lacquer deposits which are essential to produce ring sticking.

Mr Wilford has stated that carbon filling of the scraper ring slots does not occur in the Caterpillar engine; from the above observations it appears

that the bonding material (lacquer), necessary to produce carbon filling of the scraper ring slots, is deposited in the region of the scraper ring during L.1 tests, when the quality level of the oil is sufficiently low. What does appear to be absent is the combustion carbon which could adhere to the lacquer and cause scraper ring slot filling. The absence of this combustion carbon is probably due to the fact that before every L.1 test a new liner, piston, and ring are fitted, and it is possible that a quantity of combustion carbon passing the ring belt could be increased by lengthening the test or artificially simulating a worn engine condition by increasing the ring gaps. However, it is probable that Caterpillar L.1 ring belt lacquer deposits will correlate with service scraper ring filling when applied to straight mineral 2-104B quality oils, but the present procedure is not suitable for differentiating between oils of MIL-0-2104 quality in this respect, as the conditions are such that any satisfactory MII-0-2104 oil produces a virtually clean piston when tested by the Caterpillar L.1 test procedure.

A. Towle: Mr Vaile and myself hoped to arouse interest by our paper in a relatively simple, short, and inexpensive test procedure on a British engine, which, in addition to giving reasonable correlation with the present widely accepted Caterpillar L.1 test, would give results closely approximating to those obtained under widely different service conditions. Although correlation with the L.1 test is not perfect, as indeed it never can be for borderline cases owing to the complex nature of the acceptance standard, we feel that the objects of the procedure have in the main been accomplished. Users of the Caterpillar are well aware of the limited number of tests which can be carried out in a year, and intelligent use of the AV1 enables the number of unsatisfactory and expensive tests, which would otherwise be necessary, to be materially reduced.

In reply to Mr Williams' question on SAE 50 oils, experience of these oils, both on the Caterpillar and on the AV1, has indicated that, in general, they require considerably higher additive treatment than the corresponding SAE 30 oils to achieve a given performance level. From tests carried out on ring arrangements set to give various rates of oil consumption, it is concluded that the lower oil consumption of the SAE 50 oils does not provide the answer, but rather that this is bound up with the general use of high V.I. solvent-refined Brightstock in these oils.

The considerable difference between the performance of various MIL-0-2104 oils reported by Mr Richards and Mr Pearce must be expected, since some oil companies for cost reasons will wish to work to the minimum treatment level necessary for their oils to gain MIL-0-2104 acceptance, while other companies will for prestige reasons aim at a much higher standard than the minimum acceptance level. The various diagrams in the AV1 paper will bear this out.

Sulphur content of fuel is not the only property of any significance, and when using reference gas oils with physical properties necessary to meet the U.S. Army Ordnance and the British Ministry of Supply test fuel requirements, the relationship between sulphur content of the fuel and wear, ring sticking, and deposits, given in the paper, has been established. In the case of heavy residual fuels, similar tests have shown equally well that wear is much more likely to be influenced by the ash content of the fuel than by

the sulphur content, but, here again, the actual type of ash contained by the fuel will obviously influence the extent of wear.

We cannot agree with the general assumption by Mr Hughes that, in a given engine under given conditions, additive-treated oils are subject to high oil consumption. At least one well-known British diesel engine manufacturer asserts that, from the moment when the engine is first run, he achieves much lower oil consumption on additive-treated than on straight oils. I am inclined to doubt whether, other things being equal, and given a carefully run-in but unworn engine, either type of oil shows advantage over the other in the matter of oil consumption.

G. H. J. Simmons : There has been a certain amount of criticism directed against some of the papers, on the grounds that they describe engine test methods designed to correlate with the Caterpillar and Chevrolet tests only. However, these two tests are now well established as requirements in various specifications. Furthermore, they are the only tests on which a sufficient background of information is available to enable us to develop any other type of engine test for correlation purposes.

Representatives of oil companies were specifically asked for information about any screening tests they used to assess the performance of their products to avoid carrying out the much more expensive Caterpillar and Chevrolet tests in every case. Therefore, the engine test procedures described can be fully justified, even if they do not cover certain other phases of lubrication which may merit investigation. Mr Wilford has rightly said that every individual bus engine has its own problems, but we should have to develop a very great number of engine test procedures to obtain information on them all.

Dr Clayton has expressed the hope that we may be able to dispense with engine testing eventually in favour of some fairly simple chemical or physical laboratory test. I very much hope that his wish may come true, but at present a consideration of the complexity of the conditions for which one has to make provision in a laboratory test may make it simpler, although perhaps not cheaper, to carry out an engine test.

R. J. S. Perry : With reference to Mr Cree's remarks on temperature, it has been found that when an SAE 40 oil has been tested, the piston skirt temperature has risen because of the reduced amount of oil flowing on to it, and there have been more deposits in the scraper ring grooves than in the SAE 30 or thinner oils. Perhaps one of the reasons why buses or road vehicles on short journeys stick their oil scraper rings is that the piston skirt temperatures are raised, since at the idling speeds of the stopped buses, the temperature is sufficient to bake the deposits.

Another point in connexion with plugging of oil scraper rings is that possibly the oil temperature of the sump is not sufficiently high to drive off water vapour that enters the oil from the gas blow-by.

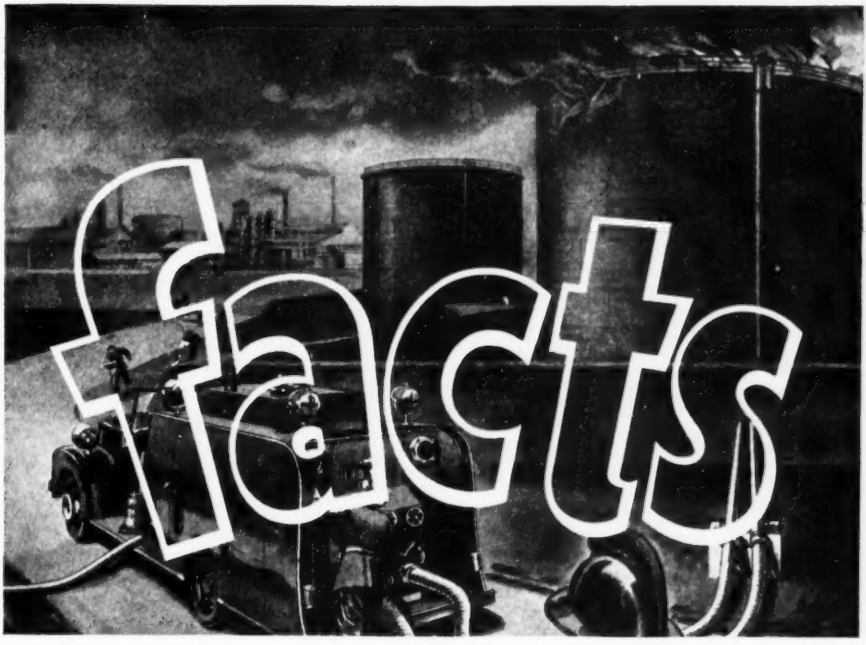
C. O. R. Bell : In reply to Mr Towle, it was realized that the difference in metallurgical structure of the copper–lead bearings mentioned in the paper might lead to some difficulties, but at the time we were unable to obtain specially made bearings for the Petter W1 engine of similar structure to

those used in the L.4 test. In practice, however, it was found that different types of additives tend to give different non-corrosive wear levels—that is, when corrosion has been completely inhibited, the lowest weight loss that one obtains varies from 10 mg with an additive which does not form a surface film, to a small gain in weight if the additive is of a type which characteristically forms a surface film of finite weight. Providing the general nature of the additive concerned is known, it is possible to judge fairly accurately whether it will pass the Chevrolet test on bearing corrosion or not. This is borne out by the fact that we have yet to run a Chevrolet L.4 test which has failed on bearing corrosion, since the Petter W1 test has rejected all unsatisfactory formulations before the L.4 test stage has been reached. It has been suggested that the work on the Petter W1 may have been limited to a narrow range of base oils and additive types. In fact, among the approximately two hundred tests carried out, base oils from many crude sources, refined by a wide range of processes, have been tested, and these have been combined and tested with additives of several basic types, ranging from premium to heavy-duty formulations. The information obtained has always been found to be invaluable in preparing formulations for the full-scale tests.

The Petter WI test should not be regarded solely on its own merits. It has proved to be most valuable when used in conjunction with the Petter AV1 test, as this combination provides screening for both the full-scale American Test Methods.

Mr C. B. Dicksee proposed a vote of thanks for the contributions to the important subject of engine testing of lubricants, and this was passed with acclamation.

Dr E. B. Evans then proposed a vote of thanks to Mr C. B. Dicksee for having taken the chair so ably. This was warmly accorded.



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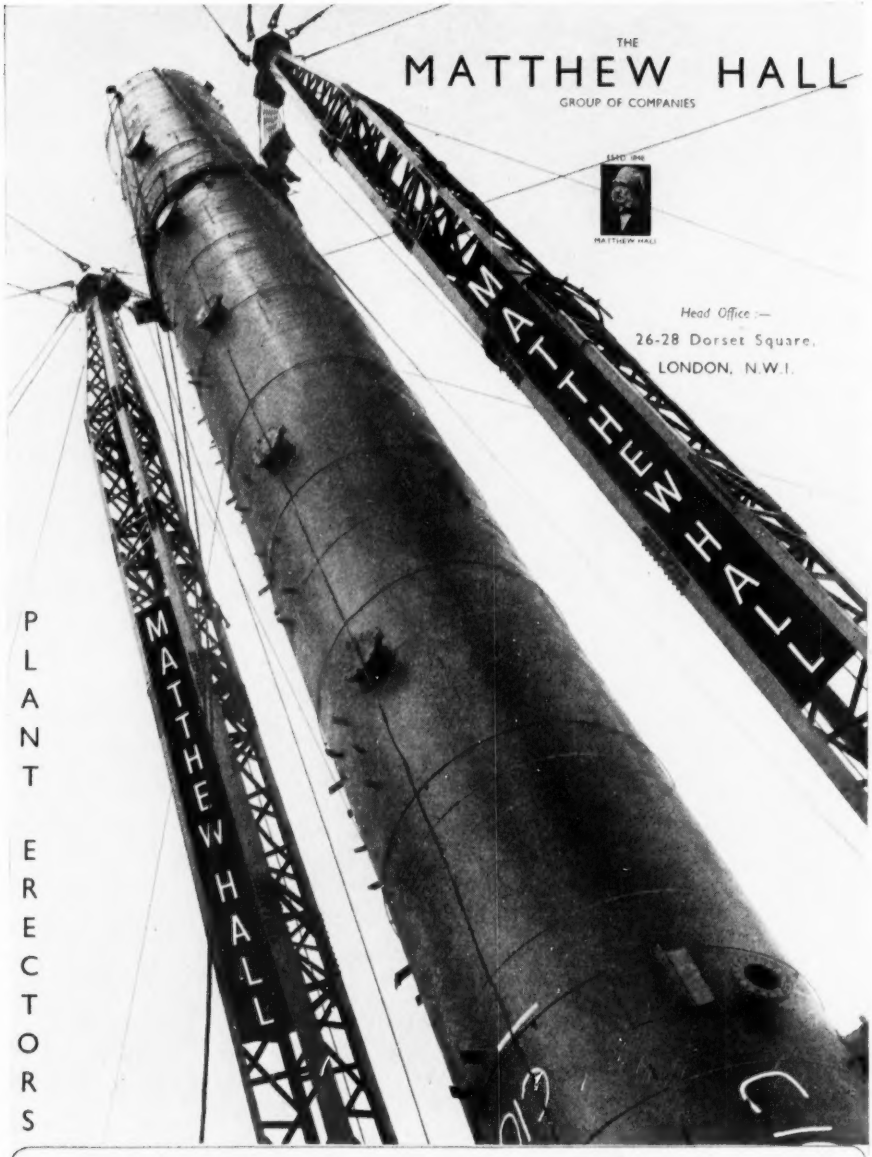

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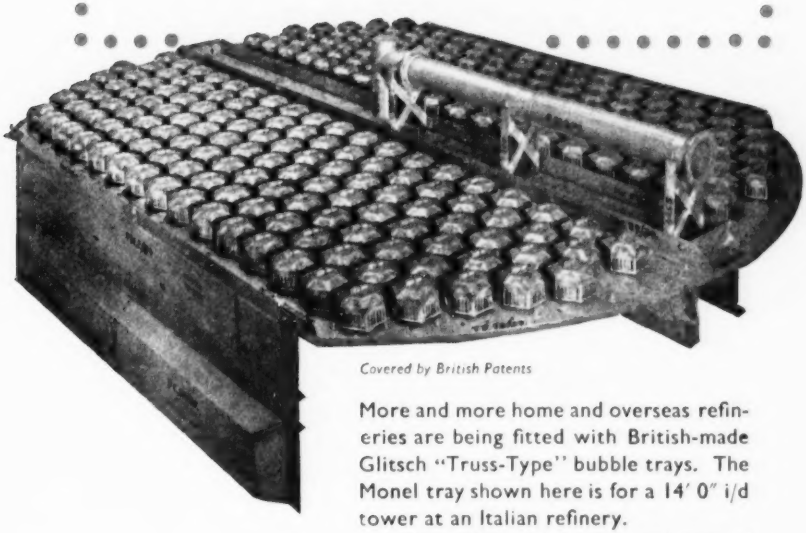

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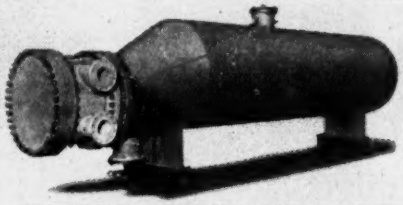

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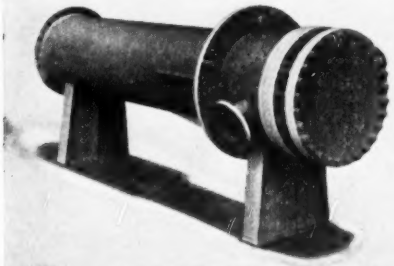

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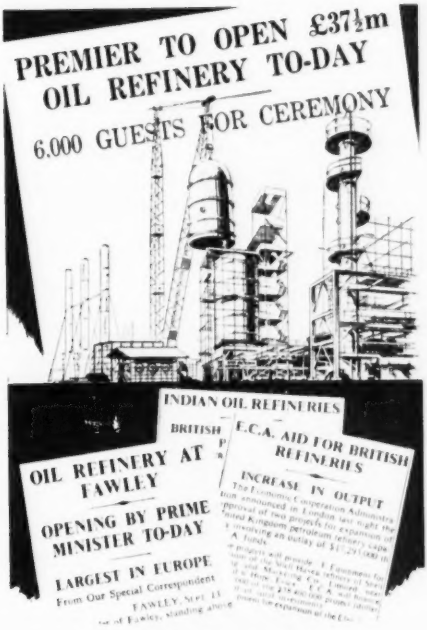
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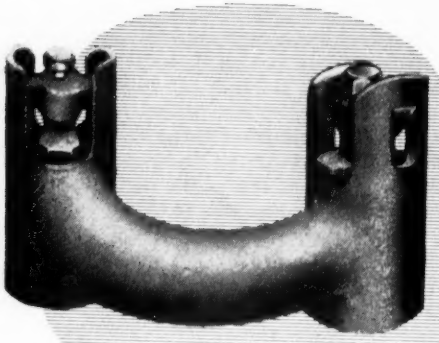

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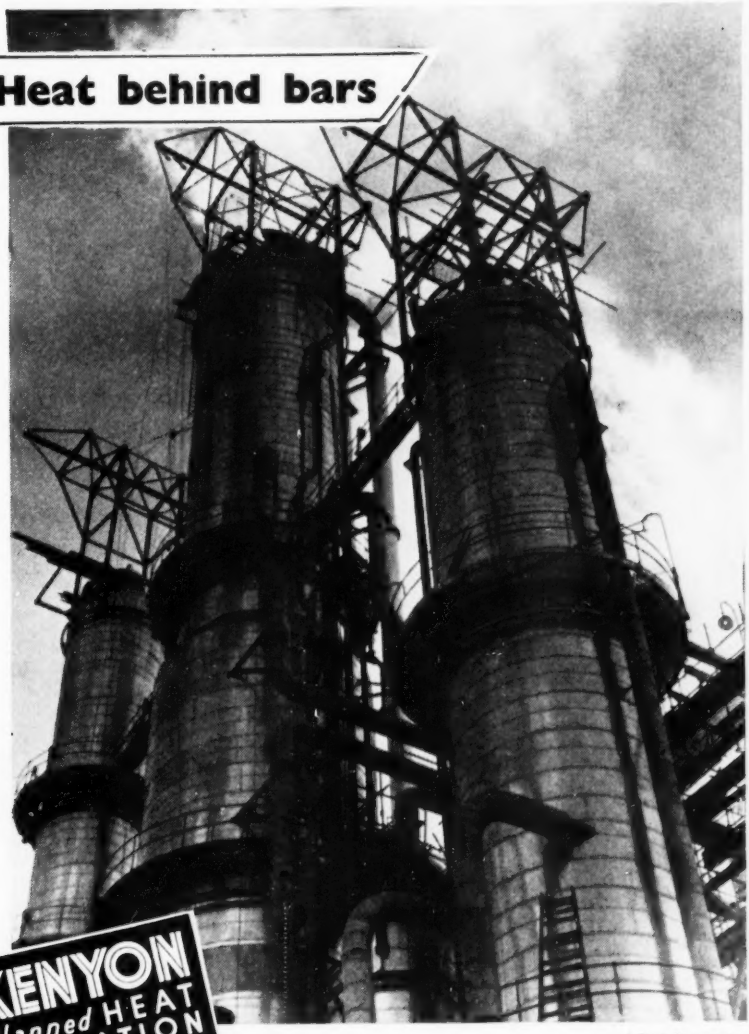

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Kenyon provide a *complete* thermal insulation service to the oil industry, including technical advice on thermal insulation specifications, and finishes for all conditions. Supply of materials, application, supervision, on sites throughout the world. The photograph shows columns on the Distillation Unit, M.E.C. project at Ellesmere Port, Cheshire.

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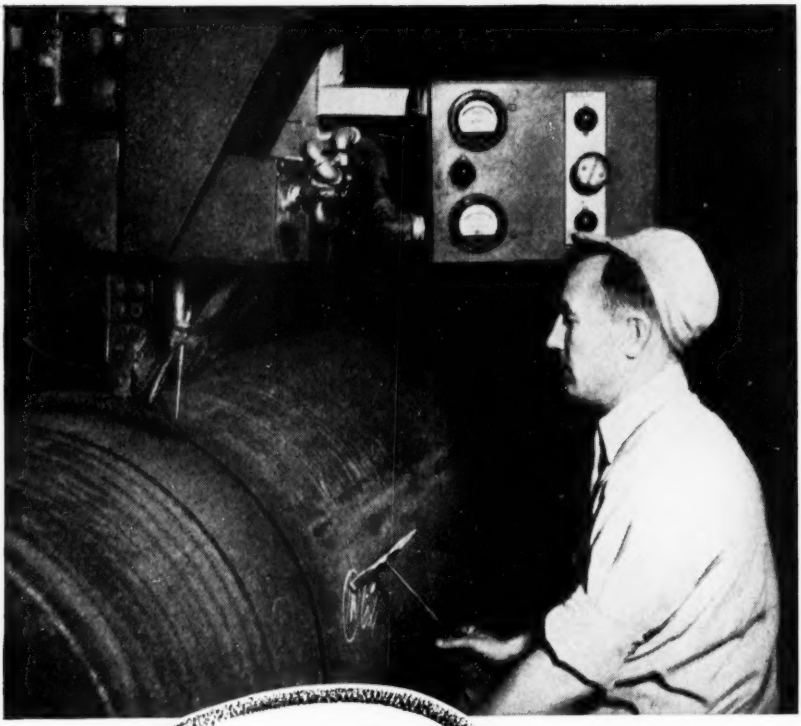

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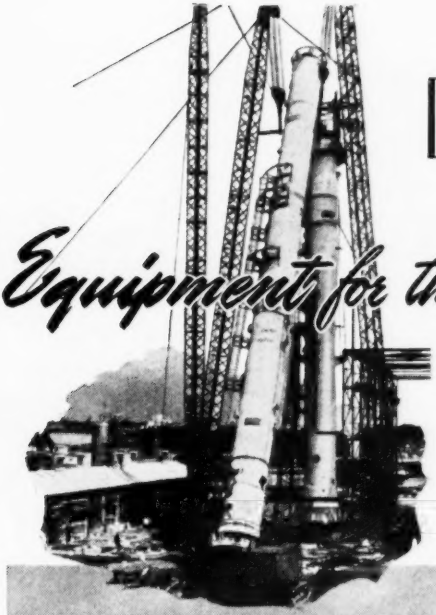

The illustrations show typical welded treating towers manufactured by Babcock & Wilcox Ltd. for new oil refineries in Britain.

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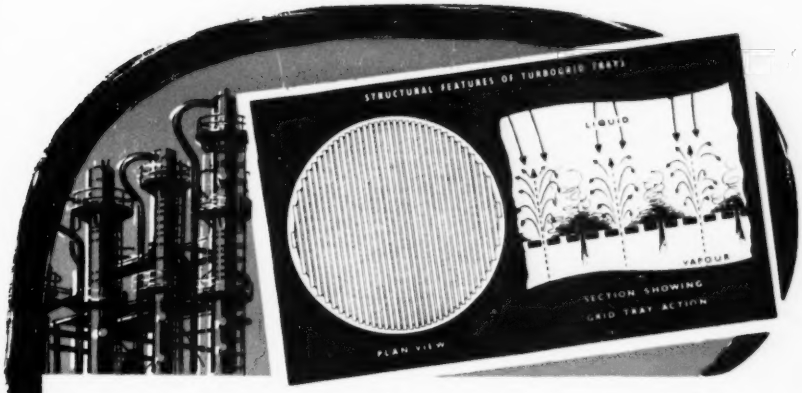

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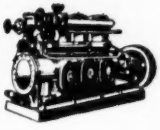

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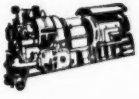

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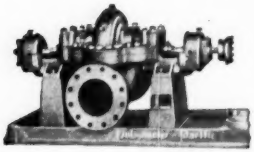

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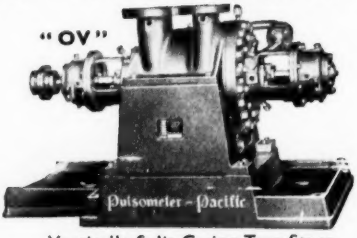

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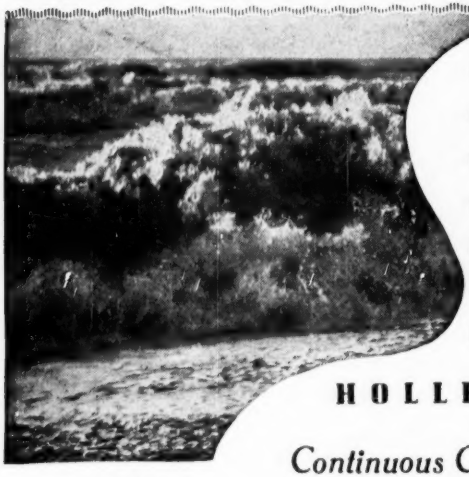

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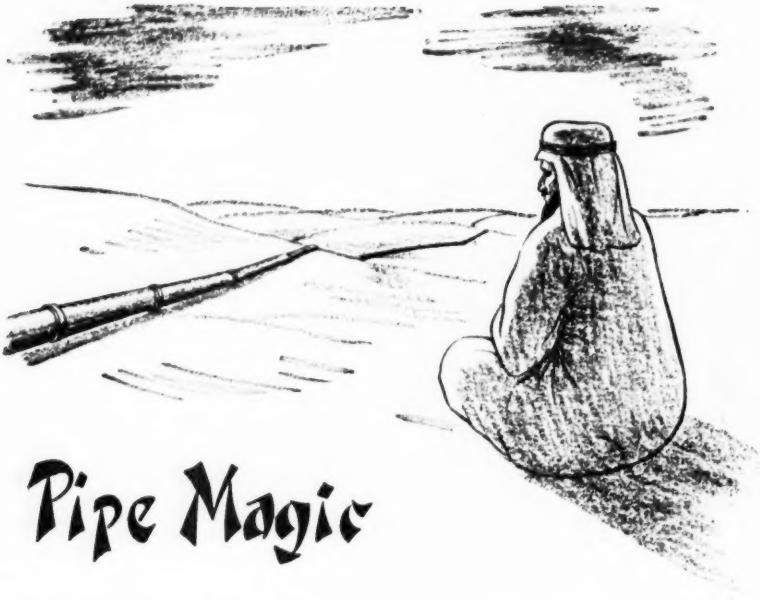

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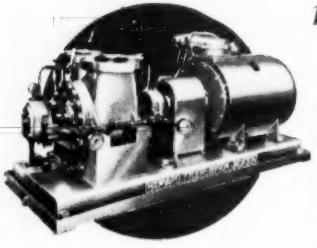

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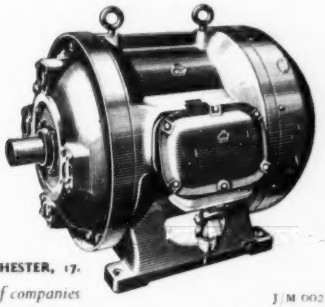

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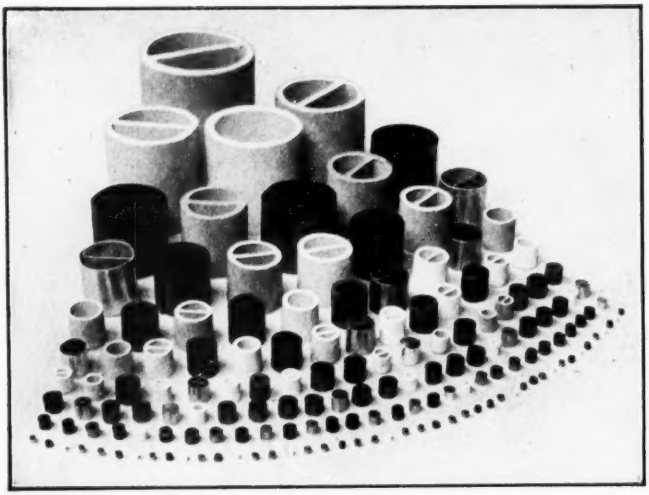

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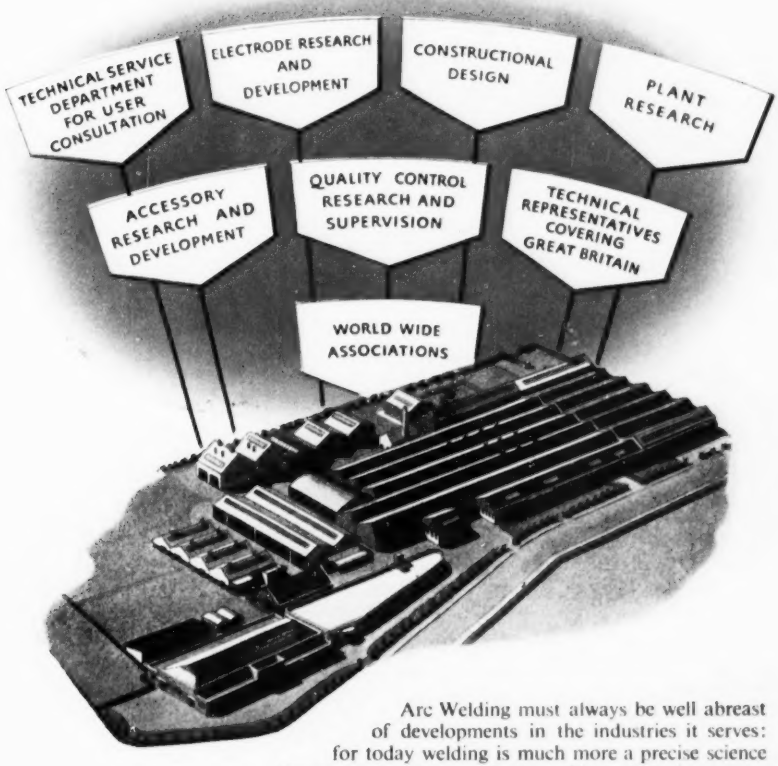

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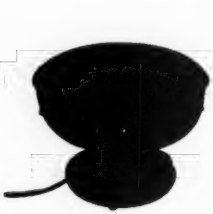

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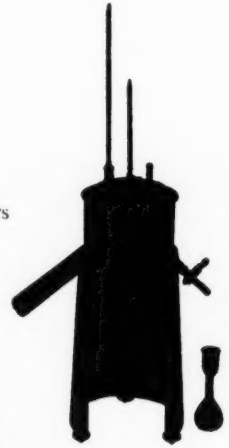

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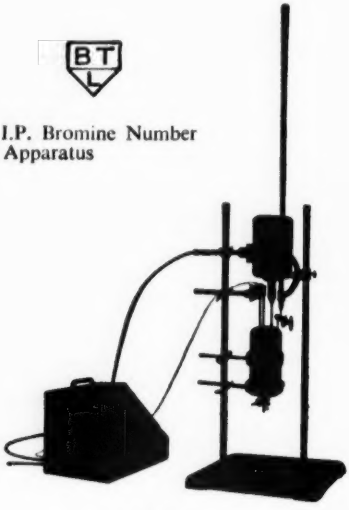

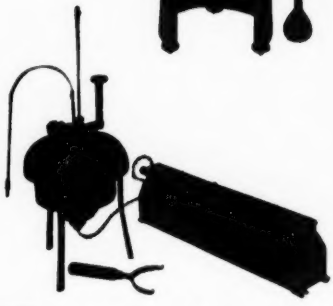

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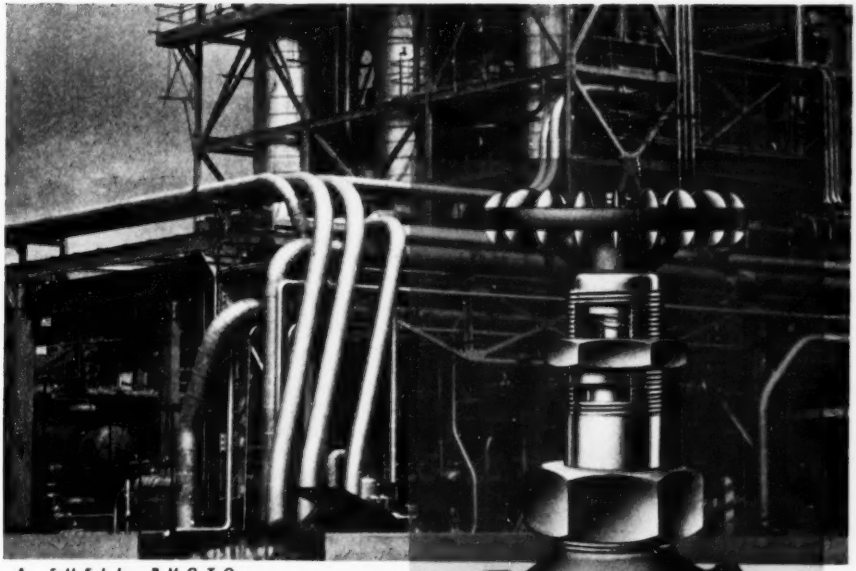

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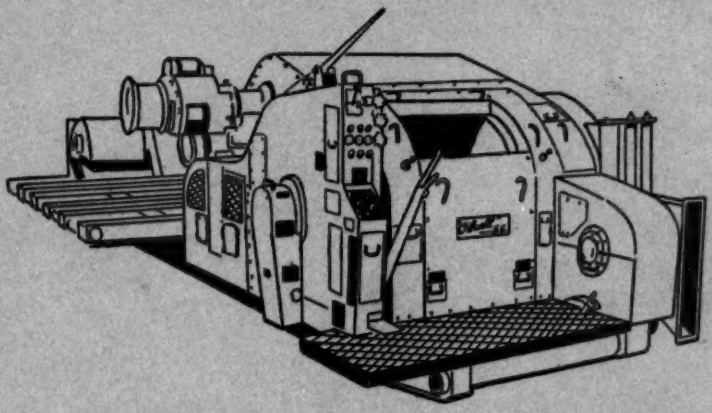

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